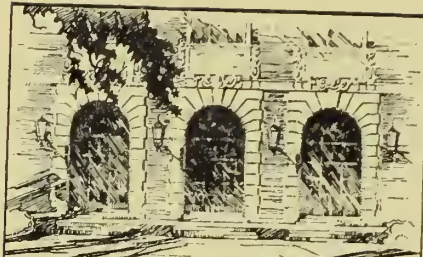


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THE INFLUENCE OF ULTRASONIC VIBRATIONS UPON THE PHYSICAL FEATURES OF ACTIVATED SLUDGE

By

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THE INFLUENCE OF ULTRASONIC VIBRATIONS
UPON THE PHYSICAL FEATURES OF ACTIVATED SLUDGE

by

Thomas Robert Wallin

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CHAPTER 1. INTRODUCTION

The activated sludge process has been defined as "a biological sewage treatment process in which a mixture of sewage and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated effluent by sedimentation, and wasted or returned to the process as needed. The treated sewage overflows the weir of the settling tank in which separation takes place" (Glossary, 1949). A large amount of research has been conducted and modifications have been made to the process in recent years. Most of this effort has been directed toward the biological process in the activated sludge aeration tank. The goals of this research include a possible reduction in required aeration tank volume and subsequent reduction in construction costs and the possibility of obtaining efficient treatment of wastes previously untreatable with the conventional activated sludge process.

The research undertaken to improve the sedimentation phase of the activated sludge process can be divided into two general areas. The first area of study was the investigation of the importance of the physical features of the sedimentation tanks, such as depth and sludge rakes. Dick (1965) has shown that the solids handling capacity of activated sludge can be improved by increasing the depth of the settling basin. Dick (1965) offered as an explanation of the benefits of increasing the basin depth and the addition of the stirring mechanism, similar to the sludge rakes, the fact that, upon settling the activated sludge forms a delicate structure. This structure exerts an upward force on all the activated sludge which is at a higher elevation in the settling basin. This force was called the structural support force.

By increasing the depth of the basin, the weight that this structural support force must carry is increased. When the load carried by the structure of the activated sludge surpasses the compressive strength of the sludge, the sludge structure will collapse. The settling rate and settled sludge density are thereby increased.

With the addition of the stirring mechanism the activated sludge structure is continuously sheared thereby increasing the settling rate and increasing the settled sludge density.

The second area of research includes studies attempting to chemically alter the activated sludge so that its settling characteristics will be improved. This area of research includes the work of Woodard and Etzel (1965) who proposed adding a coacervation agent such as acetone to the layer of bound water. Acetone is essentially infinitely soluble in the suspending medium and has practically no solubility for the colloid itself. The molecules of the coacervant mix with the molecules of the bound water and force this bound water away. Although Woodard and Etzel (1965) were using lignin for their studies. They suggested that his coacervation process could be used to reduce the bound water on activated sludge thereby improving its settling characteristics. Heukelekian and Weisburg (1956) have shown that the sludge volume index of activated sludge could be reduced if the bound water was reduced. Tenney and Stumm (1965) have suggested using polyelectrolytes, ferric chloride, and alum to improve settleability of activated sludge, which, to a point, can be considered hydrophilic biocolloids. Tenney and Stumm (1965) acknowledged the fact that bound water was an important factor in the stability of these so called hydrophilic biocolloids. In addition to the

use of chemicals to improve the settleability of activated sludge, ultrasonic vibrations have been studied as a means of accomplishing this same purpose. Sollner and Bondy (1936), Prakash and Ghosh (1962), Boyle (1928), Freudlich and Sollner (1936) and Hermans (1933) studied the effects of ultrasonic vibrations on inorganic colloids. Sollner and Bondy (1936) concluded that the particles are flocculated when exposed to ultrasonic vibrations, and the rate of spontaneous flocculation increases rapidly as the concentration increases. They also concluded that particles of different size migrate with different velocities toward the zone of accumulation, thus being liable to collisions. Zones of accumulations occur where sound waves reinforce one another. Sollner and Bondy (1936) also concluded that the particles do not migrate in one direction; their microscopic movement merely being the result of asymmetry of the oscillations which they perform according to their different sizes. Hermans (1933) theorized that the ultrasonic waves cause a distortion of the electrical double layer and a polarly charged particle is established. The results of studies by Schulte (1964) and Lyon (1952) showed that ultrasonic vibrations can improve the settleability of activated sludge. Schulte's (1964) study revealed that the longer activated sludge is exposed to ultrasonic vibrations, the more compacted was the settled sludge. Lyon (1952) found that the best settling rate resulted from 15 min of ultrasonic vibrations. Schulte (1964) and Lyon (1952) did not, however, give any explanation as to what caused the improvement in settling characteristics. Coleman and Gotaas (1951) hinted at a possible reason for the improved settleability when they stated that "the ultrasonic excitement of organic particles will break the capillary bonds

as well as change the other wastes--solids relationships to permit a more efficient dewatering." Wilson (1924) pointed out the importance of the two types of water associated with activated sludge. He described the two types of water as interstitial water, which can be forced out by the application of slight pressure and absorbed or bound water which cannot be removed mechanically except by the application of enormous amounts of pressure. It is the author's contention that Coleman and Gotaas (1951) were suggesting that ultrasonic vibrations will reduce the bound water associated with the activated sludge particles.

It is pertinent to this area of sludge thickening research to determine the actual effect ultrasonic vibrations have on the bound water of the activated sludge. There are several factors which should be considered when investigating the relationship between ultrasonic vibrations and the quantity of bound water. These factors are: the effect of the power applied to the transducers; the frequency of the ultrasonic vibrations; and the time of exposure to the ultrasonic vibrations. These factors will be described in Chapter 2.

Since previous studies (Heukelekian and Weisburg, 1956) have shown that a correlation exists between the amount of bound water and the sludge volume index and since previous studies (Schulte, 1964, and Lyon, 1952) have shown that ultrasonic vibrations could improve the settling characteristics of activated sludge, the author felt that the dissimilar variables, bound water and ultrasonic vibrations, could be interconnected. It was the purpose of this research, therefore, to determine the effects of ultrasonic vibrations on the bound water of activated sludge. Other criteria

for judging the quality of activated sludge, such as total solids in the supernatant, sludge index, and settling velocity were also considered.

In order to observe the effects of ultrasonic vibrations on the above listed criteria, the primary variables of ultrasonic vibration were varied. These variables are discussed in the following chapter.

CHAPTER 2. THEORY

2.1 General

The primary variables of ultrasonic vibration, power applied, frequency of vibration and time of irradiation, are discussed in this chapter.

2.2 Power Applied

The magnitude of the amplitude increases with an increase in power applied (Heuter and Bolt, 1955), (Carlin, 1949), and (Fredericks, 1965). Hermans (1933) derived the expression

$$b - b_o = \frac{i\omega V (S_o - S) a_o \cos\left(\frac{\omega x}{g}\right)}{W + i\omega V_s} \quad (1)$$

where a_o is the amplitude of the cyclic velocity fluctuation, $(b - b_o)$ relates to the inertia of the particles in suspension, b , and to the inertia of the suspending liquid, b_o , ω is the frequency of the ultrasonic vibrations, g is the velocity of propagation of the ultrasonic waves, S is the density of the particles in solution, S_o is the density of the suspending solution, V represents the average volume of the particles, x is the position of the particle in the medium, and W is a proportionality constant making the quantity $(b - b_o)e^{i\omega t}$ equal to the resistance force. The figure t is time of exposure to ultrasonic vibrations. The symbol i was not defined in Hermans' (1933) paper. Since he reported that the difference between the inertia of the particles in suspension and the inertia of the suspending medium, $(b - b_o)$, was proportional to the amount of resistance to movement experienced by a particle with respect to the suspending liquid when exposed to an ultrasonic

vibration, it is suggested that this resistance is instrumental in causing the resulting effects of ultrasonic vibrations.

Lyon (1952) concluded that an increase in power input to the piezoelectric crystal produced a similar increase in settleability. Piezoelectric crystals are discussed further in Section 3.23. This indicates that with increased power application to the crystal, the time period required to reach a point of maximum settled sludge concentration can be reduced.

Cavitation has been described as being primarily responsible for the effects brought about by ultrasonic vibrations (Carlin, 1949) (Brown and Goodman, 1965) (Fredericks, 1965) (Heuter and Bolt, 1955). The term cavitation was used to describe the formation of cavities in a liquid. These cavities may or may not be filled with air and vapor. The formation of cavities can be explained using Bernoulli's (1738) equation

$$(P/d) + (v^2/2g) = \text{constant} \quad (2)$$

where P is the hydrostatic pressure, d is the density of the liquid, v is the velocity of the liquid medium and g is the gravity constant. From the studies of Hermans (1933) it follows that the velocity, v, increases with an increase in power applied to the transducer. This is easy to understand if one remembers that the amplitude of vibration increases with an increase in power applied and that the frequency is kept constant. Therefore, the velocity must increase if the liquid medium and suspended particle travel farther, as a result of the increased amplitude, in the same period of time. As the velocity increases, the hydrostatic pressure, P, must decrease in order for

equation (2) to remain constant. As a result of the low hydrostatic pressure, cavities or void spaces are formed in the liquid. When the conditions responsible for these cavities are no longer present, they will collapse. In most cases, it is due to a rise in hydrostatic pressure or a decrease in temperature (Carlin, 1949). Lord Rayleigh (1917) computed the pressure developed during the collapse of a spherical cavity. He found the pressure of thousands of atmospheres may be developed at the moment when a cavity collapses to a small fraction of its original diameter. This tremendous amount of energy, which is concentrated in small areas, will logically produce very noticeable effects. It is postulated that cavitation in addition to the previously mentioned resistance is largely responsible for the effects brought about by ultrasonic vibrations.

2.3 Frequency of Vibrations

The absorption of ultrasonic vibrations in a liquid medium is known to increase with an increase in frequency (Fredericks, 1965). According to theory, absorption increases with the square of the frequency (Babikov, 1960). Therefore, it would seem logical to maintain the frequency as low as possible to prevent this needless loss of energy. Lyon (1952) used a frequency as high as 240 kilocycles per second (kc/sec) to agitate his sample. As a result of this excessively high frequency, he was able to use only a 7 ml sample. Schulte (1964) used frequencies of 48 kc/sec, 75 kc/sec and 275 kc/sec. He was able to use a 2 l sample since his lowest frequency of vibration was low enough to prevent an excessive absorption of the ultrasonic energy. Frequencies of 18.5 kc/sec, 32.5 kc/sec and 45.0 kc/sec were used in this research. The size of samples exposed to ultrasonic vibrations in this research was 3.84 l.

2.4 Time of Exposure

It is logical to expect that, as the length of time the sludge is exposed to the ultrasonic vibrations is increased, the effect produced will be more pronounced. This was shown to be true by Schulte (1964). He concluded that the longer the sludge is exposed to the ultrasonic vibrations the higher the settled sludge concentration would become. Lyon (1952) concluded that an exposure period of 15 min was the most beneficial to settling. Various exposure times were studied in this research. It should be pointed out that other than that previously mentioned in this section, little theory of the effect of increased time of exposure is available.

CHAPTER 3. EXPERIMENTAL PROCEDURE AND EQUIPMENT

3.1 Experimental Procedure

3.1.1 General

The activated sludges utilized in this research described in Appendix A were taken immediately from the sewage treatment facility to an aerated sludge reservoir in the laboratory as shown in Figure 1 and described in Section 3.2.2. Every effort was made to conduct the experiments with the sludges as soon as possible so that conditions in the sewage treatment plant could be duplicated in the laboratory.

In general, the sludge index (SI), the bound water multiple (BW), the total solids in the supernatant (TS) and the settling velocity (V) were determined on activated sludges which had been exposed to the ultrasonic vibrations as well as activated sludges which were used as controls. These determinations are discussed in Chapter 4.

Variables of ultrasonic vibration such as power input to the vibrator (transducer), frequency of vibration and time of exposure were studied to determine an optimum level for each.

3.1.2 Procedure

From the aerated storage reservoir, the activated sludge was pumped into a column used for ultrasonic exposure, as shown in Figure 1. An aerated sludge storage reservoir, a sludge pump and the necessary piping are grouped into the "Sludge Pumping System," which will be discussed in Section 3.2.2.

The power input to the transducers, which were the sources of the ultrasonic vibrations, was 25 watts for both the 45.0 kc/sec transducer and



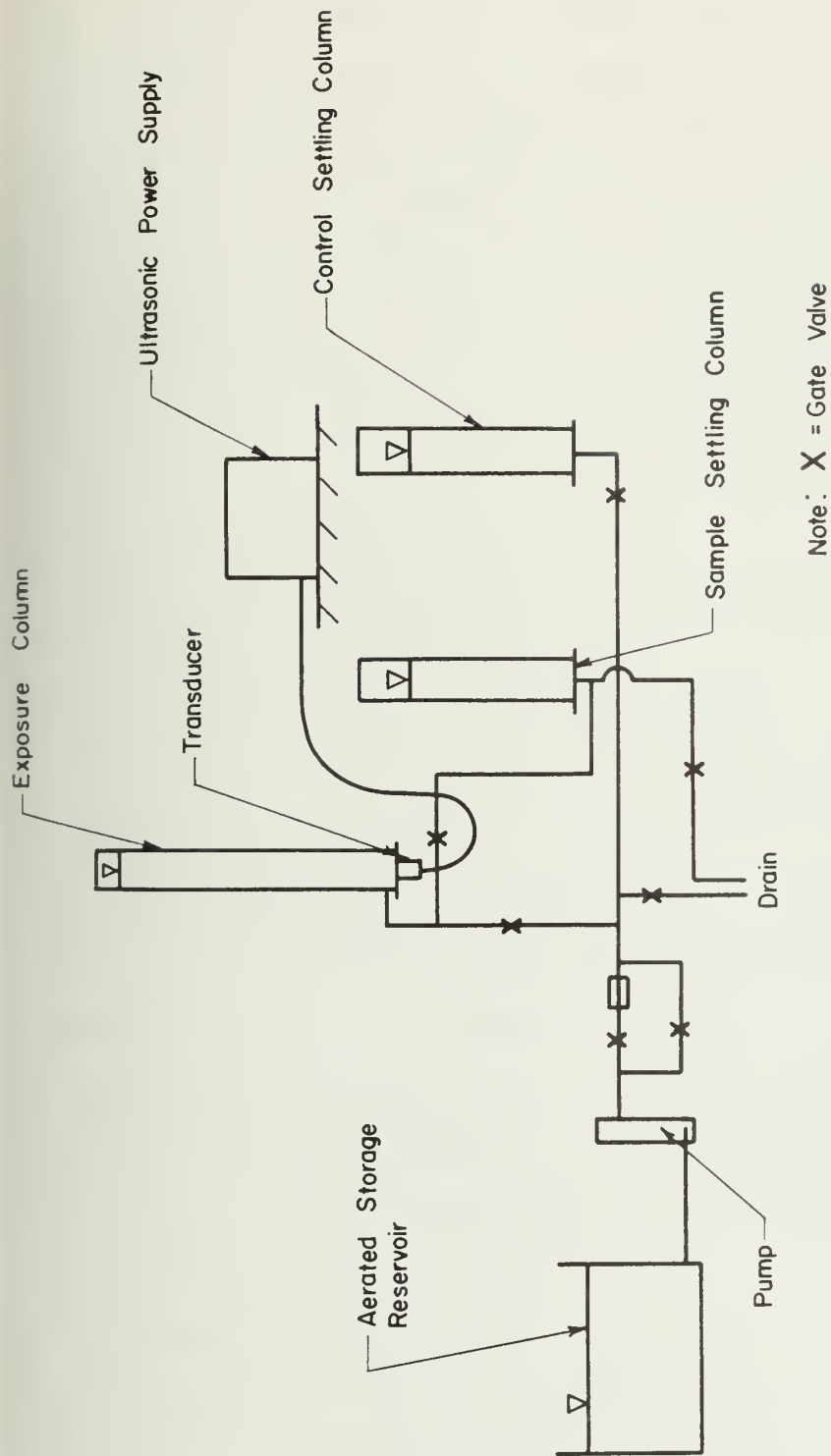


FIGURE 1. SCHEMATIC DIAGRAM OF NONANALYTICAL EQUIPMENT.

the 32.5 kc/sec transducer. The 18.5 kc/sec transducer was powered with inputs of 25 watts, 50 watts and 75 watts. The container, the transducers and the ultrasonic power supply constituted the "Ultrasonic Agitation System." A complete description of the Ultrasonic Agitation System is included in Section 3.2.3. For each combination of frequency and power input, five separate studies were conducted to determine the effect of the time of exposure to the ultrasonic vibrations. Each study consisted of the analytical procedures listed in Section 3.1.1 and described in Sections 4.2, 4.3, 4.4, 4.5 and 4.6. Of course, the effect of frequency and power input were also studied. Exposure times of 0.0 min, 0.5 min, 3.0 min, 12.0 min and 30.0 min were selected for study. Immediately following the exposure to ultrasonic vibrations, the irradiated sludge was mixed with a 4 ft manual stirrer manipulated with a combined vertical and circular motion. The activated sludge settled during the exposure when only 25 watts were applied to the transducer. As little stirring as necessary was used since this stirring might be construed to be the actual causative agent for the benefits of ultrasonic vibrations. The stirring was also carried out on the sample that followed an identical flow path as the exposed activated sludge but was not irradiated (0.0 min exposure). This was utilized to determine the effects of the stirring since the only difference between this sample and the control was stirring. The stirring was judged sufficient when the activated sludge in the exposure column appeared homogeneous. Then, the sludge was allowed to flow by gravity into the Sample Settling Column, as illustrated in Figure 1. The Sample Settling Column and the Control Settling Column are referred to as the "Settling System." The settling column fill time was maintained at 60 sec, for reasons explained in Section 4.1.2, throughout the entire period of experi-

mentation. Immediately after filling the Sample Settling Column to a depth of 1.5 ft, a 10.0 ml sample was taken for bound water analysis through the sample port 1.0 ft from the bottom. Prior to taking a sample for a bound water analysis or any other determination, the contents of the sample port were wasted. This was necessary due to the small volume of sample being taken and the fact that a large portion of the sample could be from a previous experiment.

A control study was conducted simultaneously with the ultrasonic vibration study in order to detect changes in the activated sludges brought about by factors other than ultrasonic vibration. As soon as possible after the activated sludge was pumped into the exposure column, an additional quantity of activated sludge was pumped into the Control Settling Column. A sampling procedure identical to that used for removing samples from the Sample Settling Column was used to remove samples from the Control Settling Column.

The height of the activated sludge-water interface was recorded for both the activated sludge exposed to ultrasonic vibrations and the control activated sludge for 30.0 min after the start of the settling study. This was needed to determine the sludge index of the activated sludge. Thirty-five min after the start of the settling experiment, a 20.0 ml sample for total solids in the supernatant was taken from the sample port at the 1.0 ft level after wasting a small quantity of supernatant. This procedure was identical for both the sample exposed to ultrasonic vibrations and the control. The procedure for the determination of total solids in the supernatant is described more completely in Section 4.3.

After the samples were taken for the total solids in the supernatant, the controls of both columns were made homogeneous by the use of compressed air being discharged at a point near the bottom of the columns. A 10.0 ml sample was taken from each column for the determination of total water content. A 15.0 ml sample was taken from each column in a similar manner for the determination of suspended and volatile solids. These analyses are described more completely in Sections 4.4 and 4.5.

While in a homogeneous condition, the contents of the Control Settling Column were allowed to flow back into the storage reservoir; whereas, the activated sludge exposed to ultrasonic vibrations was wasted to prevent unnecessary change in the physical characteristics of the activated sludge in the storage reservoir.

3.2 Description of Experimental Equipment

3.2.1 General

To clarify the description and usage of equipment that heretofore may have been unknown to the reader, it was necessary to include a brief description of the non-analytical type equipment used in this research. This non-analytical type of equipment included the Sludge Pumping System, the Ultrasonic Agitation System, and the Settling System.

3.2.2 Sludge Pumping System

The Sludge Pumping System, utilizing the bottom fill method, developed by Dick (1965), was built to interconnect with the Ultrasonic Agitation System and the Sludge Settling System. The Sludge Pumping System, as shown in Figure 1, consisted of a storage reservoir, which has a capacity

of approximately 40.0 l, a small centrifugal pump and motor and the necessary piping. The storage reservoir was aerated to maintain aerobic conditions and to maintain adequate mixing prior to being observed in a settling experiment. The piping was designed so that the activated sludge used for the control settling curve could be returned to the storage reservoir once the experiment had been completed. The activated sludge exposed to ultrasonic vibrations was wasted upon the completion of each phase of study.

3.2.3 Ultrasonic Agitation System

The three major components of the Ultrasonic Agitation System were the ultrasonic power supply, which supplied the high frequency, high voltage power to the transducers, the transducers, which were constructed from a material, described later, which had the property to vibrate at the same frequency as the power applied to it, and the containers to hold the activated sludge during exposure to the ultrasonic vibrations.

Before the ultrasonic power supply was suitable for this type of research, certain modifications were necessary. In its unmodified form, the power supply was the power drive supply for an ultrasonic drill. The ultrasonic generator* was capable of delivering up to a maximum of 100 watts and would provide 80 watts with a frequency range adjustable between 18 kc/sec and 26 kc/sec. The alteration, required to render the power supply suitable for this research, was the switching from a single frequency range as mentioned

*Ultrasonic Generator: Glennite Model U602, manufactured and modified by West Industries, Inc., Schiller Park Illinois.

above to three frequency ranges. This modification allowed for the use of three separate frequencies when agitating the sludges. Each of these frequencies could be adjusted with an accuracy of approximately ± 5.0 kc/sec with the tuning control. The power supply, also, was equipped with an ammeter for adjusting the tuning and gain controls. The gain control was utilized to adjust the total power output of the entire agitation system. The tuning control was utilized to adjust the frequency of vibration of the ultrasonic power supply.

The transducers* were lead zirconate-lead titanate ceramics. These ceramics possessed a property known as the piezoelectric effect. The piezoelectric effect, first described by Curie (1880), is the property of certain crystals and ceramics which, when subjected to a pressure or tension, develop electrical charges on their surface. The reverse of this, or the reverse piezoelectric effect, was of more interest to this research since it was necessary to agitate activated sludge with ultrasonic vibrations. The reverse piezoelectric effect, first described by Lippmann as discussed by Carlin (1949), is the property of some crystals and ceramics to undergo mechanical oscillations when a voltage is applied to their surfaces. According to Ny Tse Ze (1927), the change in dimension of the piezoelectric crystal is proportional to the voltage applied. Going one step further, remembering that power applied, P , follows the expression

$$P = EI, \quad (3)$$

* Transducers manufactured to the author's specifications by West Industries, Inc., Schiller Park, Illinois.

it becomes obvious that, with constant current, power applications is of primary importance with regard to the dimension change of the piezoelectric material where E is the voltage applied and I is the current applied. This dimension change results in an increase or decrease in amplitude of the ultrasonic wave. When a voltage is applied across a piezoelectric slab of material, the slab undergoes a mechanical deformation which is directly proportional to the voltage applied. If the proper face is made negative with respect to the other face, the slab will contract; if the same face becomes positive, the slab will expand. The characteristics of piezoelectric materials, as derived experimentally, are expressed by the expression

$$X = dE \quad (4)$$

where X is the deformation in meters, E is the total voltage applied and d is a constant which was derived experimentally (Goldman, 1962).

The containers holding the activated sludge during exposure to the ultrasonic vibrations were somewhat larger in volume than the volumes of activated sludge exposed by Lyon (1952) and Schulte (1964). The use of the larger containers was permitted by utilizing frequencies lower than have been previously reported.

Since it was not possible to obtain transducers that were submergible, it was necessary to obtain piezoelectric crystals and attach them to the bottom of the Ultrasonic Exposure Column. If certain precautions are taken, this method of attachment can provide a very efficient means of energy transfer. These necessary precautions are: (a) use bottom material that is as thin as possible, (b) use the proper bottom material, (c) use the proper techniques and adhesive to attach the crystal to the container and (d) use activated sludge depths equal to an even number of half wavelengths.

In order to reduce the attenuation as much as possible the bottom plate should be made as thin as strength requirements permit (Babikov, 1960). Attenuation has been defined as the loss of energy during the passage of an ultrasonic wave (Carlin, 1949); therefore, it would seem logical to reduce this needless loss of energy as much as possible. Stainless steel is used in most ultrasonic liquid agitation systems such as ultrasonic cleaning and was adopted for this research. Stainless steel attenuates the sound energy only a small amount and has the strength for high power applications.

To insure that a satisfactory connection between the piezoelectric crystal and the stainless steel bottom was obtained, the following procedure was used. The stainless steel column bottom and the metal edge of the crystal were first scarified with a wire brush. This was done so that a roughened surface would face the epoxy* adhesive, used to bond the crystals to the stainless steel plates, and a satisfactory bond would result. The scarification was followed by alternate flushings with distilled water and acetone. The acetone rinse was the final rinse and was allowed to evaporate. The epoxy was carefully mixed in equal portions and approximately 20 ml of the mixture were applied to the stainless steel plate immediately after the acetone had evaporated. The transducer was forced against the plate in a twisting fashion, forcing all but a very thin layer of epoxy to the side. Air bubbles in the epoxy would greatly weaken the bond; therefore, caution (Heuter and Bolt, 1955) was exercised to prevent the entrapment of air when forcing the crystal against the epoxy and stainless steel plates. The curing of the epoxy bond was accelerated by placing the plexiglass column, the

*EPOX-E Steel Resin, manufactured by Woodhill Chemical Corp., Cleveland, Ohio.

stainless steel plates, the transducer and the epoxy in an oven at 60°C. This oven curing was also intended to force some of the accidentally trapped air out of the epoxy (Frederich, 1965). This procedure was followed on all three exposure columns.

The three stainless steel plates with the crystals attached were secured to the test columns by first forming a seal* on the bottom of the column flange. This type of sealant was chosen over rubber gaskets due to the hardening effect of ultrasonic vibrations on the rubber gaskets (Marshall Schrablow, 1966). Once the rubber seal had set the stainless steel plates were fastened to the column bottom with 1.25 inch by .25 inch bolts and wing nuts.

Carlin (1949) stated that the energy generated in a liquid medium reaches a maximum when the distance between the bottom of the column, which was the stainless steel plate, and the upper surface of the liquid is a whole number of half wave lengths. Woods (1939) confirmed Carlin's statement when he said that the technique of getting maximum energy into a bath is to adjust the depth so that the energy builds in the form of standing waves. This is accomplished by making the depth equal to a whole number of half wave lengths. These suggestions were followed in this research. The dimension of one half the wave length was calculated by

$$\frac{\lambda}{2} = \frac{c}{2f} \quad (5)$$

where λ is the wave length, c is the velocity of the ultrasonic wave in the medium which was assumed to be water and f is the frequency. The velocity of

*Dow Corning Silastic Bathtub Caulk, manufactured by Dow Chemical Company.

ultrasonic waves in activated sludge was not available, but it should differ very little from that of water. There were three different frequencies utilized in this research; therefore, there were three different half wave dimensions. An attempt was made to manipulate the number of half wave lengths for each frequency so that the liquid depth was as near as possible to 24.0 inches. The results was a depth of 24.3 inches for all three frequencies used in this research. Each transducer and stainless steel plate was attached to identical 3.5 inch, inside diameter plexiglass* columns. Both ends of each column were fitted with flanges having standard bolt hole arrangements. The volume of the columns is approximately 1.901 per ft of depth, or, approximately 3.851.

3.2.4 Settling System

In order to observe the sludge as it settled, transparent plexiglass columns, such as those described previously, were utilized. The columns were equipped with sample ports located every 6 inches along the 1.5 ft length of column. The sample ports consisted of 1 inch diameter holes plugged with a stopper containing a short section of 10 mm glass tubing terminated with a piece of rubber tubing and a pinch clamp. Sampling ports were flush with the inner wall of the column.

*Type HC-205 Cast Acrylic resin tube manufactured by Rohm and Haas Co., Philadelphia, Pa.



CHAPTER 4. METHODS AND MATERIALS

4.1 Uniform Suspended Solids Concentration

4.1.1 Introduction

It is possible for the increase in the settling rate and the decrease in the sludge index, when compared to a control, to have been caused by the failure of the researcher to obtain a uniform distribution of suspended solids rather than being caused by ultrasonic vibrations. The turbulence occurring at the time of filling can cause the settling velocity and sludge index to vary slightly depending on whether the fill rate is too fast or too slow. Figure 2 represents laboratory data which exemplifies this.

The small quantities of activated sludge used by Lyon (1952) would tend to reduce the effects of a non-homogeneous solids profile. However, this was not substantiated. Also, Schulte (1964) did not determine whether he had obtained a uniform suspended solids profile when the turbulence subsided in his studies with ultrasonic vibrations. To remove any doubt that the improved settling characteristics brought about by ultrasonic vibrations may be actually due to the failure of the researcher to attain a uniformly dispersed suspended solids concentration, it would be desirable to investigate exactly what could be done to accomplish this.

4.1.2 Technique--Control

A technique developed by Dick (1965) was used to obtain a uniform distribution of suspended solids at the end of the apparent flocculation time. The apparent flocculation time will be described later in this section.

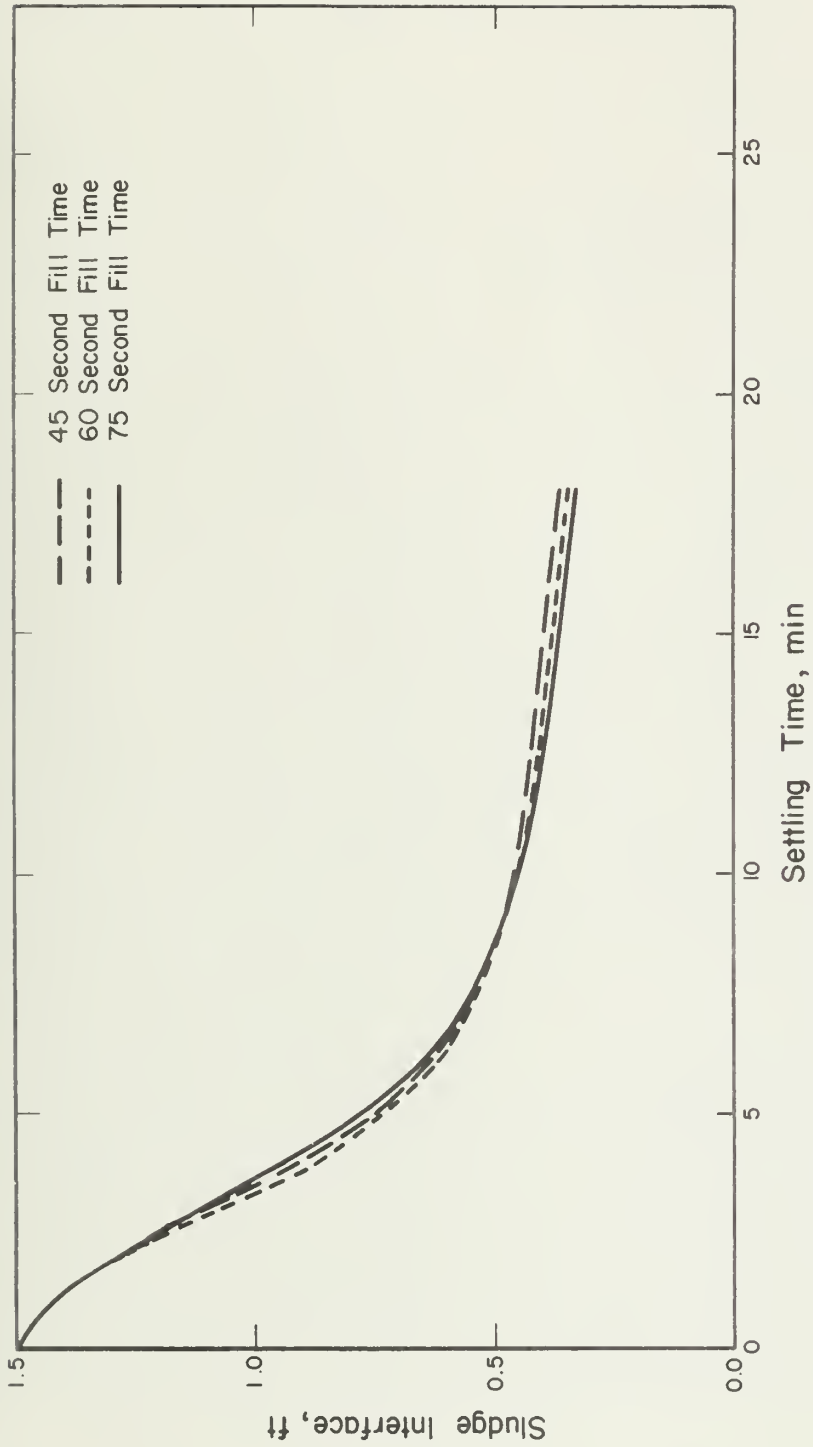


FIGURE 2. EFFECT OF VARIOUS FILL TIMES

Since a column height different from that used by Dick (1965) was used for this research, the following procedure, essentially identical to that of Dick's (1965) with the exception of the column height, was used to establish another fill time. This technique involves pumping the activated sludge through a port in the bottom of the column at a rate which would minimize the nonuniformity of the solids profile.

In brief, the time required to fill the column, which would give a uniform suspended solids profile, was established by setting a fill time, obtaining a suspended solids profile at time $T = 0$, which is the end of the fill time, plotting the sludge-water interface height vs time curve to determine the apparent flocculation time and then obtaining a solids profile at the end of the apparent flocculation period. If the solids profile was not uniform at the end of the apparent flocculation period, a new fill time was established and the previous procedure was repeated.

The initial solids profile, obtained at $T = 0$, was made by repeatedly filling the settling column and immediately taking a 15.0 ml sample of activated sludge after first wasting a small quantity which could have been left from the previous filling operation. This was repeated three times to get samples at elevations 0.1 ft, 1.0 ft, and 1.4 ft.

A typical batch settling curve, as illustrated in Figure 3, for flocculent materials will aid in describing the determination of the apparent flocculation time. A short lag period can be seen before constant rate, zone, settling commenced. The point at which the continuation of the constant settling velocity portion strikes the horizontal continuation of the original sludge-water interface level is defined as the apparent flocculation time, T_f .

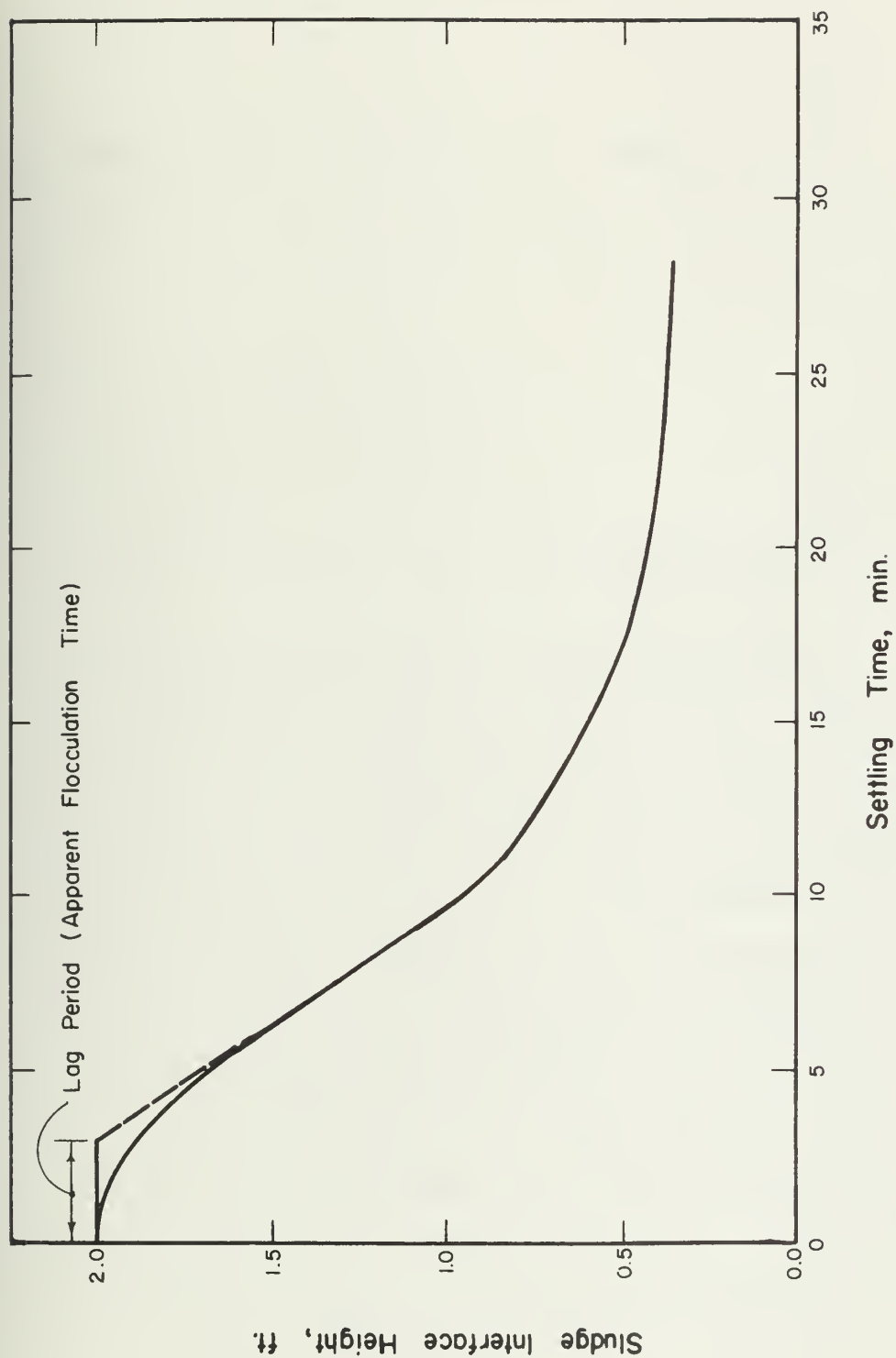


FIGURE 3. SLUDGE WATER INTERFACE, APPARENT FLOCCULATION TIME.

The solids profile taken at the apparent flocculation time was obtained by filling the column in the same time as used when determining the initial solids profile and the sludge-water interface vs time curve. If the solids profile at this fill was uniform to the extent that all points of the solids profile were within the 95 percent confidence limits (Standard Methods for the Examination of Water and Waste Water, 1965), the fill time used would be utilized in all later filling procedures. If any of the points were outside the 95 percent confidence interval, as determined using samples taken after 0.00 min settling, the entire procedure was repeated using another fill time. Figure 4 shows solids profiles at fill times 45 sec, 60 sec, and 75 sec. As can be seen in Figure 4, a fill time of 60 sec produced the required uniform suspended solids profile and was used in all subsequent filling operations when settling characteristics were to be studied.

4.1.3 Technique--Sample Exposed to Ultrasonic Vibrations

Initially, there appeared to be very little value in determining a fill time for the column exposed to ultrasonic vibrations, because the action of these ultrasonic vibrations would seem to prevent any further flocculation and settling during exposure. However, it became apparent after preliminary investigations that some sedimentation and flocculation did take place during exposure to the 32.5 kc/sec and 45.0 kc/sec frequency vibrations. Figures 5 and 6 show the solids profiles from these preliminary investigations. Each exposure was made at approximately the maximum power available for the transducer utilized. The maximum power input to the transducers with frequencies of 18.5 kc/sec, 32.5 kc/sec, and 45.0 kc/sec were respectively 75 watts, 25 watts, and 25 watts. Since a uniform suspended solids profile could not be

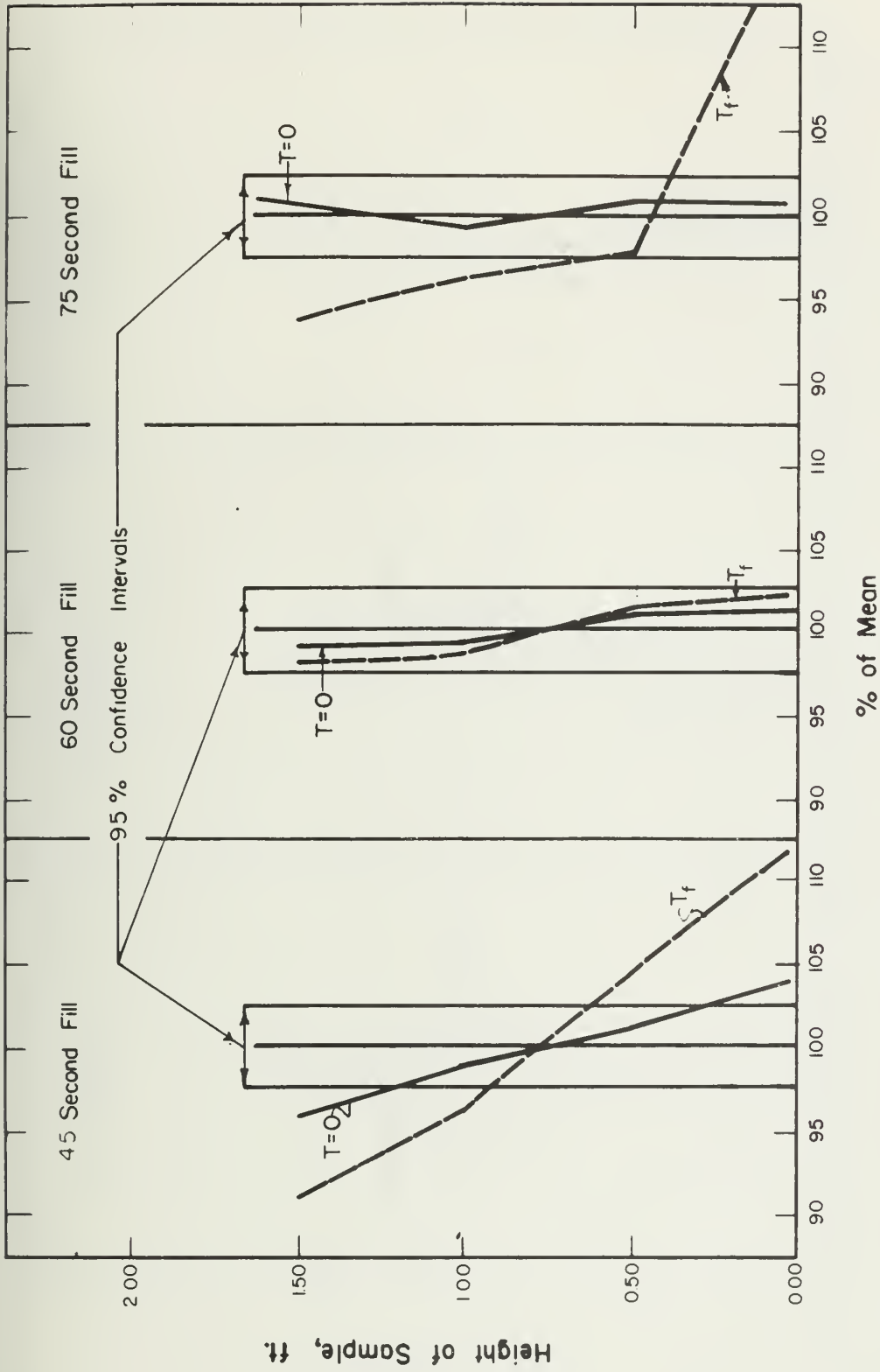


FIGURE 4. SOLIDS PROFILE.

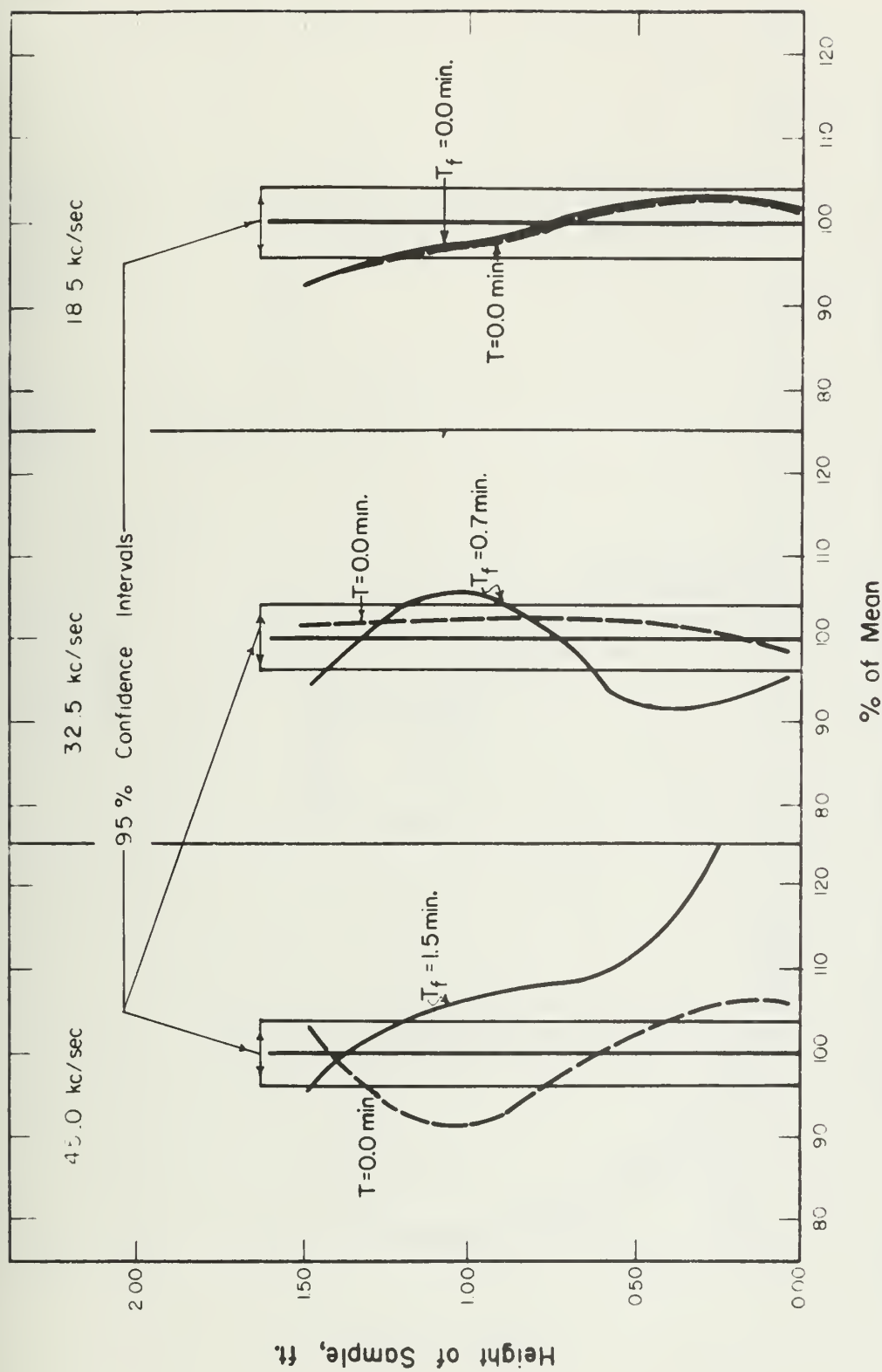


FIGURE 5. SOLIDS PROFILE FOR ACTIVATED SLUDGE EXPOSED 15 SECONDS TO ULTRASONIC VIBRATIONS.

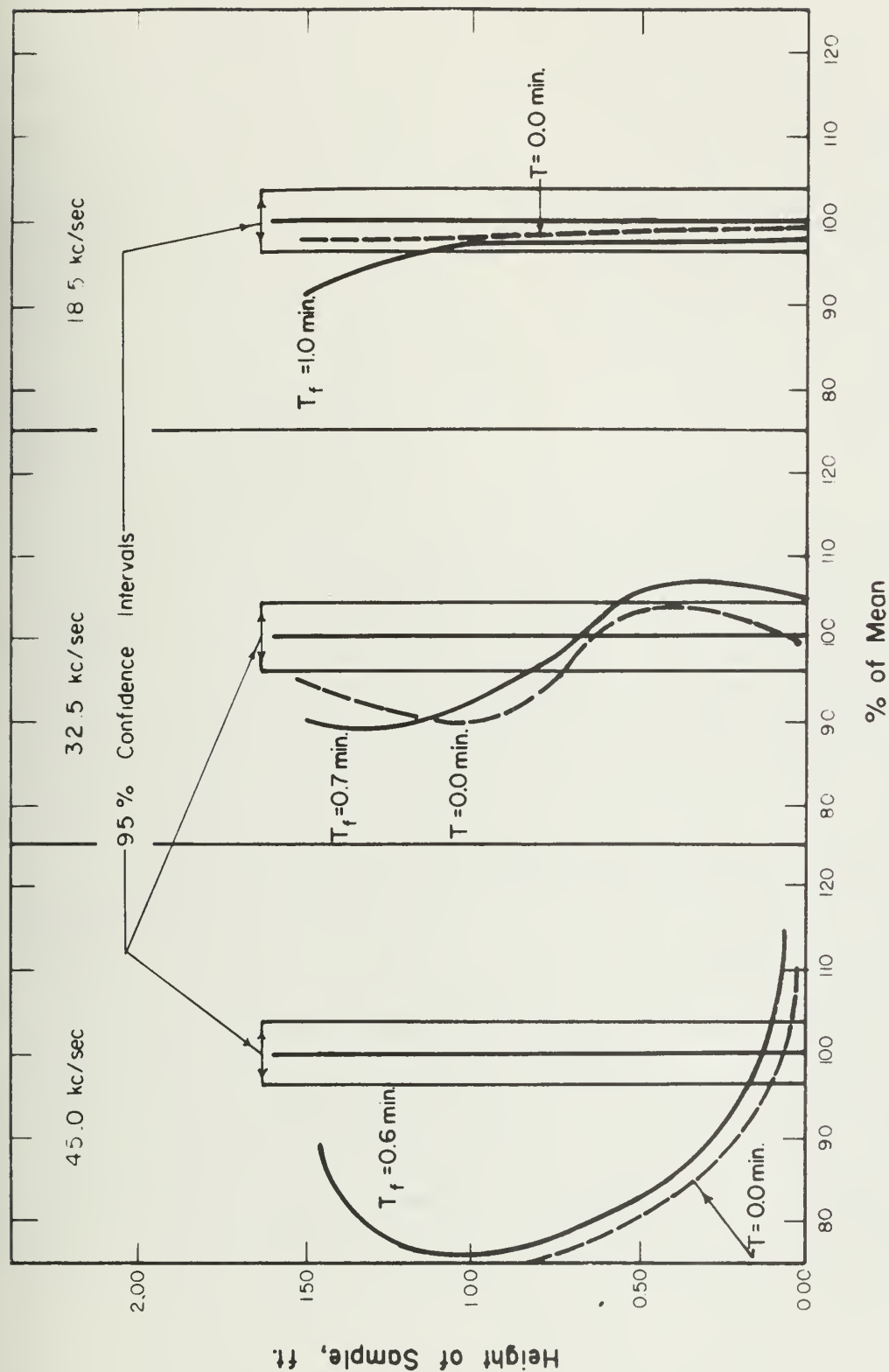


FIGURE 6. SOLIDS PROFILE FOR ACTIVATED SLUDGE EXPOSED 10 MINUTES TO ULTRASONIC VIBRATIONS.

obtained with ultrasonic vibrations alone and since a uniform suspended solids profile was necessary, provisions were made using the bottom fill method, as described in Section 3.1.2, to provide the uniform suspended solids profile. The activated sludges, exposed to the ultrasonic vibrations, were mixed to uniformity by hand with as little agitation as possible and allowed to flow by gravity into another identical column, previously defined as the Control Settling Column, in the same fill time as experimentally determined in the previous section.

4.2 Dilatometer Method for Bound Water

4.2.1 Introduction

This technique, used for determining bound water, was first described in the literature by Bouyoucos (1917) and Foote and Saxon (1916) and first used in the sanitary engineering field by Heukelekian and Weisburg (1956). The dilatometer method of measuring bound water is based on the theory that bound water does not freeze at temperatures below the freezing point of free water.

In most suspensions there are two types of water--bound water and free water (Jones and Gortner, 1927). Free water is considered to be water attached in no way to hydrophilic particles in an aqueous media.

The techniques developed by Moran (1932) and Lloyd and Moran (1934) indicate that, in the case of protein, one fraction of the bound water is firmly fixed, possibly by chemical bonds. The other fraction of this water is gradually frozen as the temperature is lowered and, according to Fisher (1936), is dependent upon the activity of the water in the suspension in

question. The actual limit or the amount of this latter fraction, loosely bound water, depends upon the activity of the suspending water. Since the activity of the free water is a function of temperature and the foreign material present, the free water activity will differ in the various experimental situations. Hence the limit of this loosely bound water will differ as described. Lloyd and Moran (1934) concluded that the water in this range is held as a mantle of water around protein molecules, possibly as a poly-molecular adsorption film. The water is oriented, because of the dipolar structure of the water, around the charged amine and carboxyl groups on the surface of the protein molecule and polysaccharide capsular material; hence, this water has a reduced activity. The reduction in activity is a function of the distance of the water molecule from the charged protein molecule.

In the range nearest the charged protein, the water is more firmly held (Lloyd and Moran, 1934). Jones and Gortner (1927) showed that even when the temperature is lowered to -78°C , the bound water does not freeze. It is reasonable to conclude that a chemical linkage exists for this fraction of the bound water and the colloidal material (Fisher, 1937). Lloyd and Phillips (1933) state that X-ray analysis of proteins indicate that bound water is localized around specific points.

Before going into greater detail describing the procedure for determining the quantity of bound water it would be of benefit to the reader if the dilatometer technique for bound water determinations was described in brief. If the total water and free water were known, then the bound water could be determined by finding the difference between them. The total water was obtained by drying a sample of activated sludge at 103°C for a minimum of 5 hours. Five

hours was selected for the drying time arbitrarily. Free water was determined by noting the expansion caused by the freezing of a known quantity of sludge. The expansion caused by the water-ice transformation was corrected to its free water equivalent and the bound water was calculated.

4.2.2 Laboratory Equipment

The laboratory equipment utilized in the bound water studies consisted of 2 dilatometers and a temperature control device, as illustrated in Figure 7. The dilatometers were basically similar in design to the instruments used by Heukelekian and Weisburg (1956) except for two features. The calibrated stems used to measure small volume changes were calibrated to 0.01 ml and had a capacity of 1.00 ml. The calibrated stems used by Heukelekian and Weisburg (1956) also were calibrated to 0.01 ml. However, they had a total capacity of 2.00 to 3.00 ml. The effect of the additional stem capacity will become apparent later in this section. The second modification in the design as used by Heukelekian and Weisburg (1956) was the addition of a stopcock. The stopcock was added to facilitate filling the dilatometers with distilled water or toluene. This eliminated most of the difficulty in adjusting the liquid level in the calibrated stem and to let out air bubbles that had become entrapped in the distilled water or the toluene during the filling process.

The temperature control device was used to determine the temperature of the contents of the dilatometers during the cooling and freezing operations. This instrument was identical to the dilatometers with the exception of the stopcock being absent and the addition of a thermometer in place of the calibrated stem. Two identical thermometers were utilized for temperature control. The

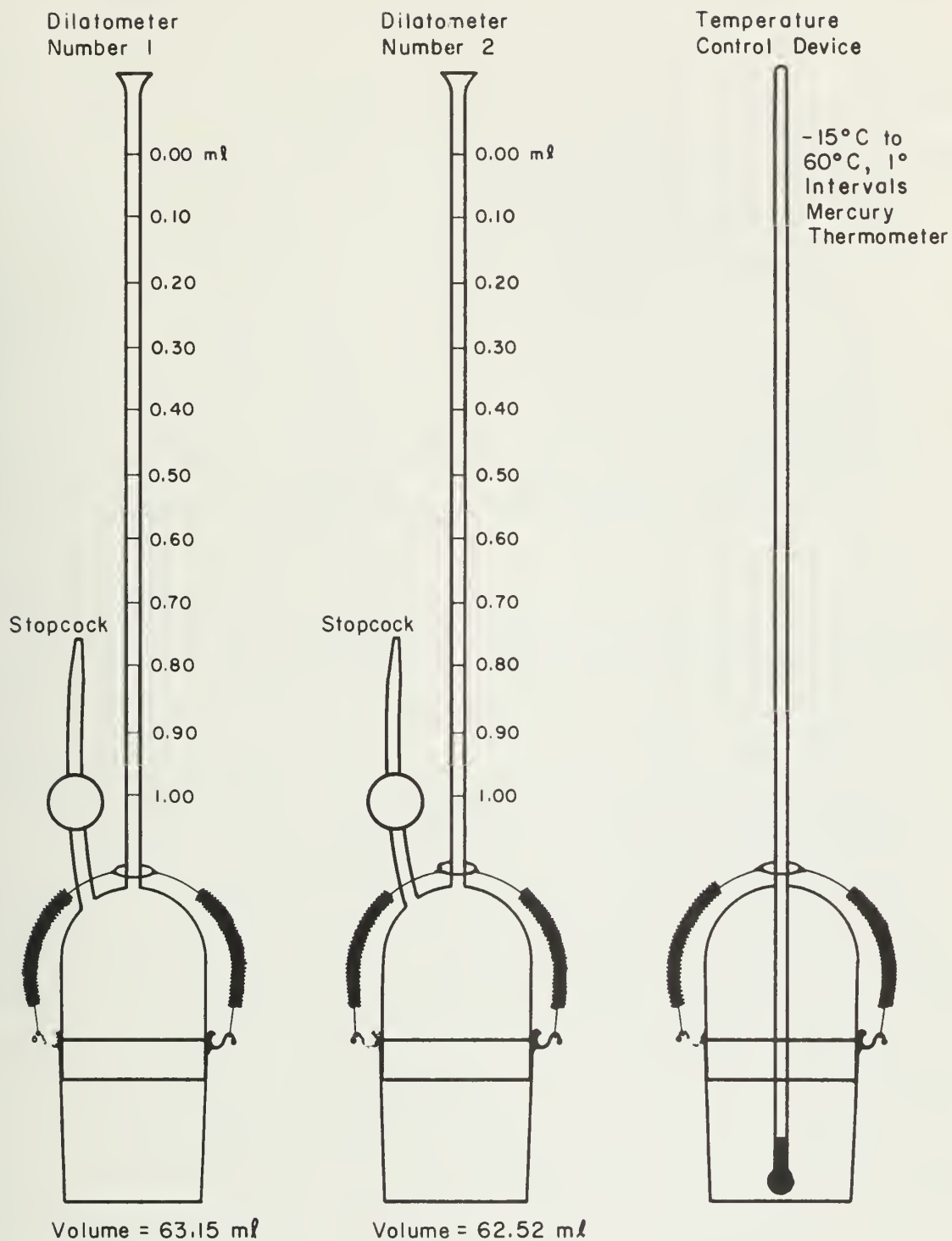


FIGURE 7. DILATOMETERS AND TEMPERATURE CONTROL DEVICE.

first, as previously described, was used on the temperature control device. The second thermometer was utilized to determine the temperature of the alcohol bath. The alcohol bath is discussed in Section 3.2.8. Since there was always some delay in a change in the temperature of the alcohol bath becoming apparent on the temperature control device, a thermometer submerged directly into the alcohol solution proved useful in maintaining a constant temperature.

4.2.3 Container and Insulation

A 1500 ml pyrex beaker was used as a container for the alcohol cooling solution. Excessive warming of the alcohol solution was prevented by utilizing a modified styrofoam acid shipping crate as insulation.

4.2.4 Uniform Temperature

Uniform temperature conditions were maintained by mixing the alcohol bath with a magnetic stirrer.

4.2.5 Volume of Dilatometers

To avoid the necessity of measuring the volume of liquid each time a bound water determination was to be made, the volumes of the dilatometers were measured using distilled water at room temperature. Prior to the addition of the stopcock, difficulty was encountered upon the addition of the distilled water into the dilatometer. It was suggested by Jones and Gortner (1927) that the water would flow down a wire extending the entire length of the calibrated stem while allowing the displaced air to escape. This did not prove successful. Coating the wire with a liquid detergent to reduce the surface activity of the water, thus the width of the water stream flowing through the calibrated stem, did not sufficiently reduce the stream width; therefore, the displaced air was not able to escape. Alternately, heating the dilatometer to expand the air

inside and then supplying water to the mouth of the calibrated stem followed by cooling the dilatometer to cause the air inside to contract was also tried. The distilled water, which was added to the top of the calibrated stem, would, then because of the vacuum, be pulled into the bottom portion of the dilatometer. This operation, however, was much too time consuming to be of much use in the many bound water determinations necessary. To facilitate ease in allowing the air to escape, a stopcock was added. This modification did allow for the rapid filling of the dilatometer. The volumes, as measured using this technique, were 63.15 ml for Dilatometer Number 1 and 62.52 ml for Dilatometer Number 2.

4.2.6 Toluene Contraction Curve

In a brief previous discussion it was pointed out that in order to determine the bound water content of a sludge, the free water content and the total water content of a sludge had to be determined first. As was mentioned earlier, the free water was determined by noting the expansion of the freezing sludge. Since freezing sludge would be destructive to the dilatometer if added in quantities that would be indicated on the calibrated stem, a small amount of sludge was utilized and an indicating liquid was added to a level that would appear in the calibrated stem.

The dilatometric method for determining bound water has wide and various applications in sanitary engineering as well as in many other fields of study. Because of these varied applications, it was reasoned that an indicating liquid of universal availability should be utilized. In addition to the condition of universal availability, the indicating liquid should possess the following characteristics (Heukelekian and Weisburg, 1956) (Jones

and Gortner, 1927):

- (a) must be immiscible with water.
- (b) must have a specific gravity less than water.
- (c) must be liquid at the lowest temperatures employed.
- (d) must have a linear contraction curve throughout the temperature range employed.

The crude petroleum utilized by Heukelekian and Weisburg (1956) was not universally available, although it met the other requirements listed above.

Jones and Gortner (1927) and Fisher (1936) revealed that toluene possessed the qualities necessary for the indication liquid. Based on these findings, toluene* was selected as an indicating liquid for the bound water studies. It should be pointed out that toluene is soluble in water to the extent of 500 mg/l (Handbook of Organic Industrial Solvents, 1961).

Experimental determination of the contraction curve for toluene was necessary since precise data for the contraction of toluene were not available. The toluene contraction curve was utilized to determine the contraction per unit volume of toluene. If the contraction of a specific amount of toluene was known for the temperature range between 1.0°C and -10.0°C , the volume of expansion undergone by the free water, when freezing, could be determined by subtracting the level of toluene in the calibrated stem that should have occurred at -10°C with the volume of toluene actually used from the level of the toluene in the calibrated stem at -10°C for the particular bound water determination.

* Manufactured by Mallinckrodt Chemical Works, St. Louis, Mo., New York, New York, and Montreal, Canada. Analytical reagent.

Figures 8 and 9 show the toluene contraction curves for dilatometers 1 and 2. The experimentally determined contraction curves were extended down to a temperature of -11.0°C .

As can be seen in Figures 8 and 9, the toluene contraction curves were started with the toluene level at 0.00 ml. The temperature was maintained at each level until no further change occurred in the toluene level in the calibrated stem. The lowest temperature reached was -11.0°C .

4.2.7 Toluene--Water Curve

To determine the expansion, a known amount of distilled water would undergo when frozen, the toluene-water curve was experimentally determined. Since the expansion caused by the freezing of the free water was greater than the contraction of the toluene in the temperature range of this experiment, the final level of the toluene at -10.0°C was above the scale provided by the calibrated stem, if the initial toluene level was 0.00 ml, as can be seen in Figure 7. In order to facilitate using the calibrated stem, the initial toluene level was lowered. This was possible since only the portion actually submerged in the alcohol bath was used to calculate the contraction of toluene. The dilatometers were always submerged to the lowest calibration mark which represented a contraction of 1.00 ml. The recorded levels of toluene at the particular temperatures were always corrected so that the value appeared as though the level of toluene was 0.00 ml at 1.00°C and dropped linearly from there. A typical toluene-water curve and corresponding data are shown in Figure 10 and Table 1, respectively. It is obvious from Figure 10 that the points recorded at 0.0 and -3.0°C could not have been read directly on the calibrated stem, unless the initial toluene level was lowered as

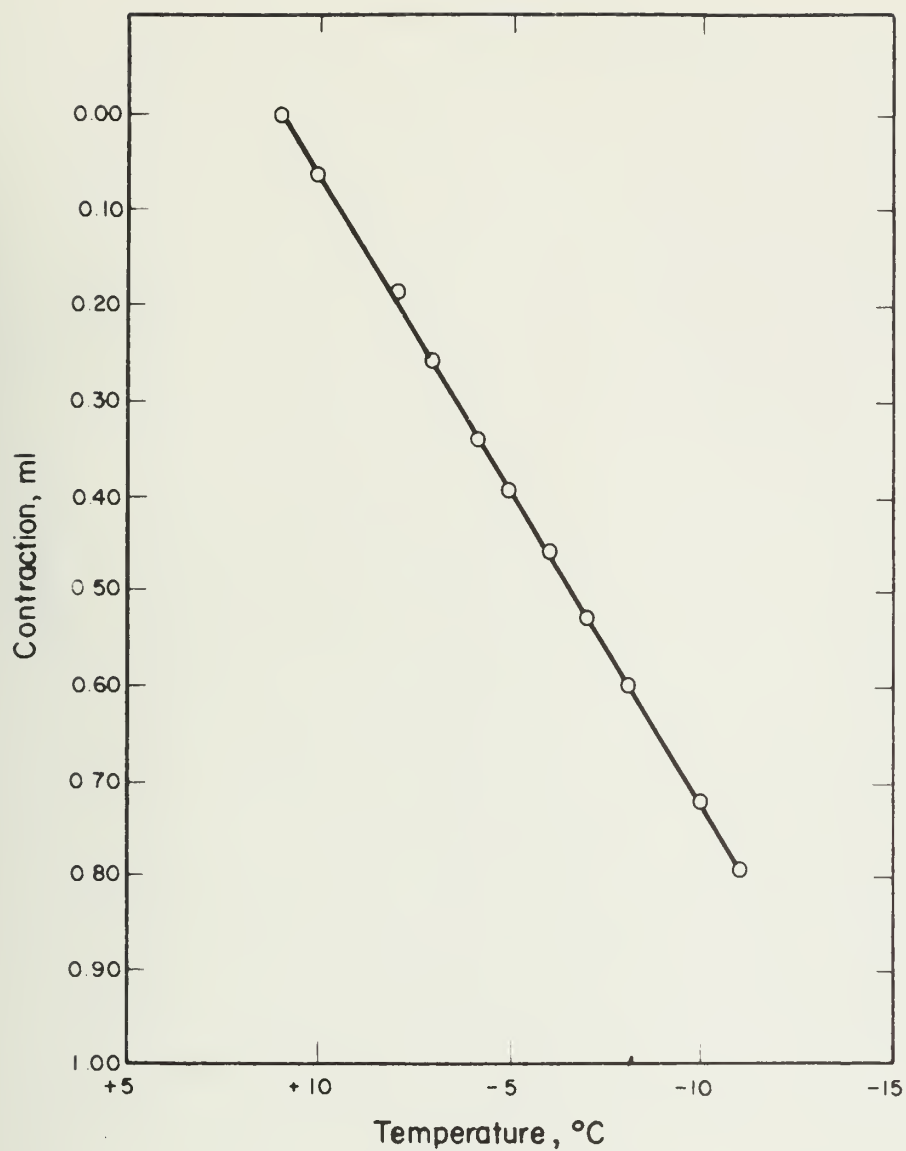


FIGURE 8. TOLUENE CONTRACTION CURVE,
DILATOMETER NUMBER 1 .

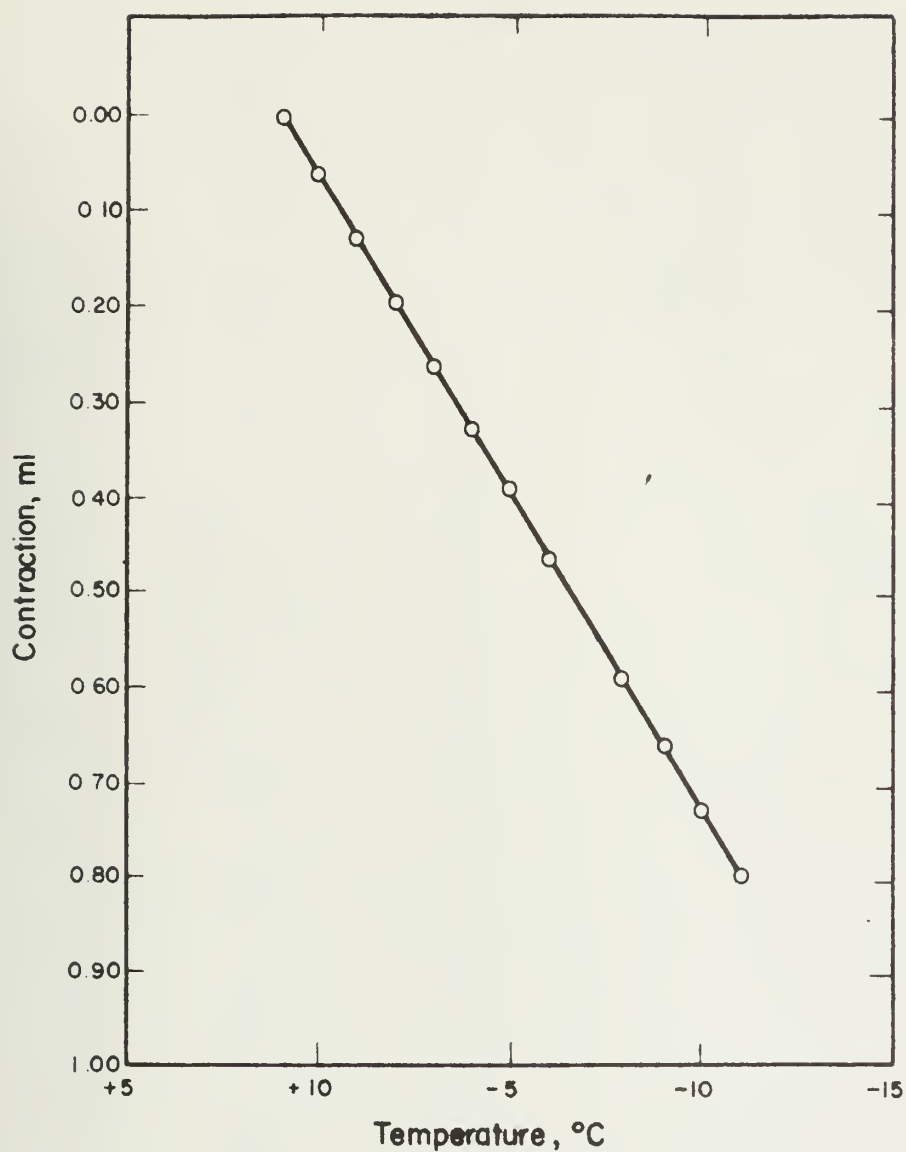


FIGURE 9. TOLUENE CONTRACTION CURVE,
DILATOMETER NUMBER 2 .

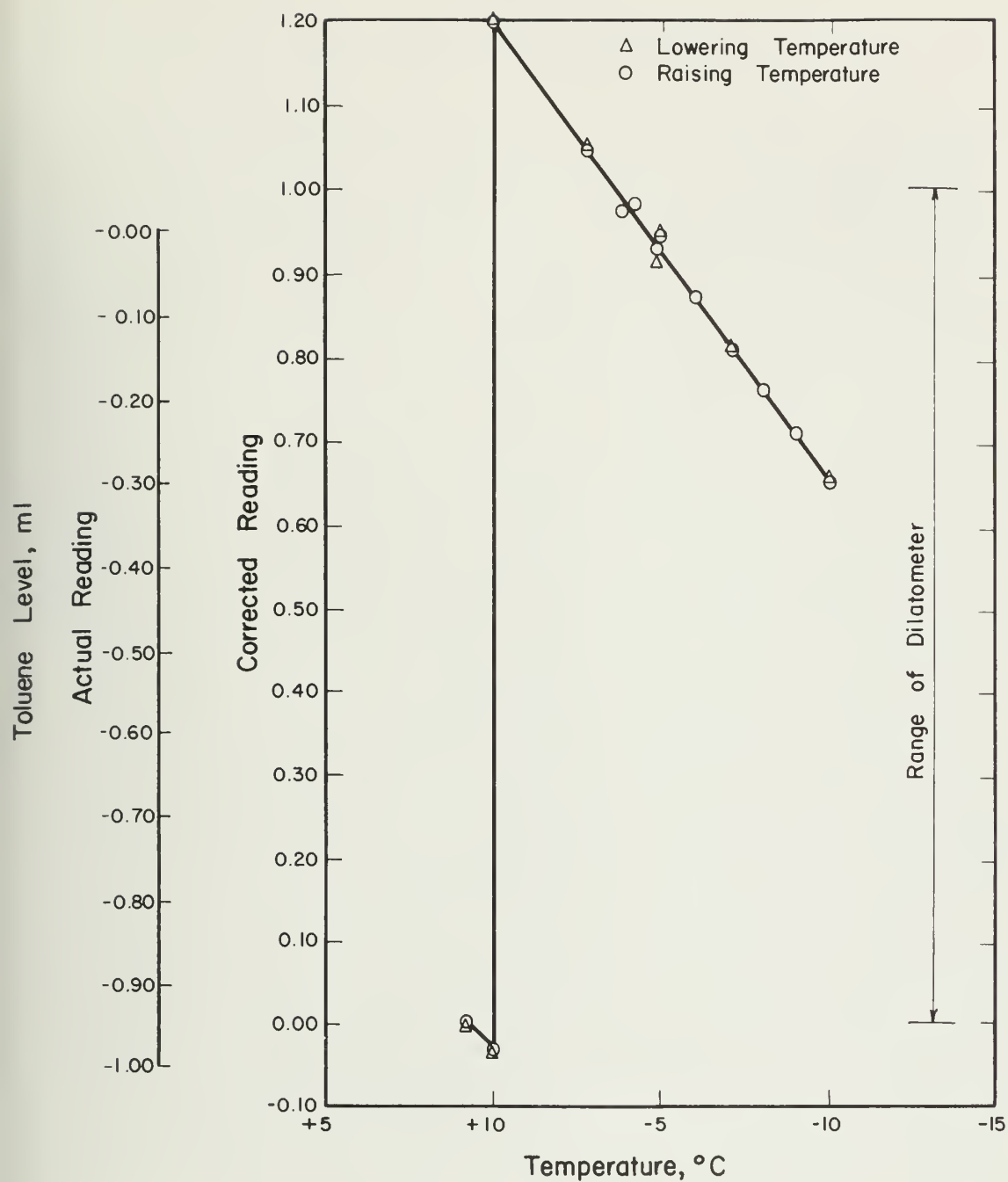


FIGURE 10. TYPICAL TOLUENE - WATER CURVE.

TABLE 1
DATA FOR TOLUENE-WATER CURVE

Actual Level, ml 1	Corrected Level, ml 2	Temperature, °C 3
-0.950	0.000	+1
-0.970	-0.020	0
+0.245	+1.195	0
+0.075	+1.025	-3
-0.007	+0.943	-5
-0.137	+0.813	-7
-0.302	+0.648	-10
-0.250	+0.700	-9
-0.192	+0.758	-8
-0.137	+0.813	-7
-0.081	+0.869	-6
-0.028	+0.922	-5
+0.016	+0.966	-4
+0.037	+0.987	-4

$$-1 \times (-0.950) = \text{Correction Factor (C.F.)} = 0.950$$

$$1 + \text{C.F.} = 2$$

previously described. The distance from the actual experimental level of the toluene to the top of the calibration was measured. The volume was determined by multiplying this length times the volume per unit length of the calibrated stem.

4.2.8 Expansion of Free Water

In order to determine the amount of bound water present, it should be recalled from Section 3.2.6 that free water is determined from the difference between the level of toluene that should have occurred at -10.0°C with the volume of toluene actually used and the level of toluene in the calibrated stem when both toluene and the material being investigated were in the dilatometer. A typical computation illustrating this procedure is provided later in this section. Once the amount of expansion was known, the volume of water which caused the expansion could be computed. In order to make this computation, it was necessary to determine the amount of water which actually expanded upon freezing. A literature survey of previous data for the amount of expansion occurring per unit volume of water frozen revealed a range of values from an expansion of 0.0911 ml per ml of water to an expansion of 0.10 ml per ml of water. The entire list and the sources are shown in Table 2. There were several explanations of the wide variations observed in the expansion of water upon freezing. Ladue (1906) concluded that as more and more air was removed from the water, the smaller the amount of expansion observed upon freezing. Barnes (1901) found a smaller amount of expansion occurring upon rapidly frozen water. Nichol (1898) stated that the results vary more than the probable error of observation so divergencies must be due either to inherent errors in the methods or to different forms of ice.

TABLE 2
EXPANSION OF WATER UPON FREEZING

Expansion, $\frac{\text{ml}}{\text{ml of water frozen}}$	Reference
0.0896	Vincent (1902)
0.0896	Ledue (1906)
0.0897	Fisher (1937)
0.0911	Vincent (1902)
0.0921	Vincent (1902)
0.1000	Heukelekian and Weisburg (1956)

The expansion per unit volume of water was experimentally determined for this research since there was such a large variation in values reported.

This was done by first placing a small quantity (5.0 ml) of toluene in the bottom section of both dilatometers and the temperature control device. Ten ml of distilled water were carefully pipetted into the bottom sections, the tip of the pipette being below the surface of the toluene. This technique prevented the collection of air bubbles at the toluene-water interface. The ground glass joints were then coated with silicone stopcock lubricant. This was followed by fitting the top portions into place. Spring connectors were used to make the joints secure. The dilatometers were filled by attaching the calibrated stems to ring stand clamps while the remainder of the toluene was added from a 50 ml burette. The complete laboratory apparatus is shown schematically in Figure 10. After filling the dilatometers at room temperature, they were separately removed and checked for air bubbles. The air bubbles, if present, were removed by tipping the dilatometers and allowing the bubbles to rise out the stopcock or by allowing the bubbles to escape along a copper wire protruding through the calibrated stem. The stopcock was closed immediately after allowing all of the air to pass through.

Once the bubbles were removed, the dilatometers were submerged in an alcohol bath. Instead of using dry ice to lower the temperature of the alcohol bath, a more efficient and economical means was utilized.

The dry ice method for controlling temperature, contrary to the studies of Dunn (1929), Latimer (1929), and Jones and Gortner (1927), proved to be relatively tedious. It was difficult to remove small pieces of dry ice from the alcohol bath once the temperature was lowered to the desired level. An alternative to the dry ice method of freezing was developed which eliminated

the difficulty in removing the coolant once the desired temperature was reached. The super cooled alcohol method was initiated and utilized in this research. This method required a freezer capable of reaching very low temperatures (-35°C). The freezer was located near the point of application in the laboratory. This procedure proved to be very economical and simple compared with the dry ice method.

To make the initial calibrated stem reading, the alcohol bath was lowered to 1.0°C by adding the supercooled (-35°C) alcohol to the alcohol bath. The alcohol, warmed by its contact with the atmosphere, was siphoned from the bath to allow for sufficient capacity for additional supercooled alcohol. The siphoning apparatus is shown in Figure 11. The level of the toluene was adjusted to read approximately -0.500 ml . (A minus stem reading indicated that the level of toluene was below the 0.000 ml level. A positive reading indicated that the level of the toluene was above the 0.00 ml level.) The toluene level was set at -0.500 ml level at 1°C because the level of the toluene would have been above the calibration on the stem at -10°C if the initial, 1°C level, was 0.000 ml . The initial 1.0°C stem reading was then multiplied by (-1.0) and used as a correction to the final, -10°C , toluene level in the calibrated stem. Table 1 illustrates this procedure.

Table 3 shows the data used to calculate the expansion upon the freezing of distilled water. As previously stated, the positive values for the corrected final readings indicate that if the process had been started at the 0.000 ml level at 1°C , the indicated quantity would have been above the 0.000 ml level. The Toluene Only Level column indicates the contraction that would have occurred if the same volume of toluene was cooled in a dilatometer with a capacity of 10.00 ml less than it actually contained. The difference

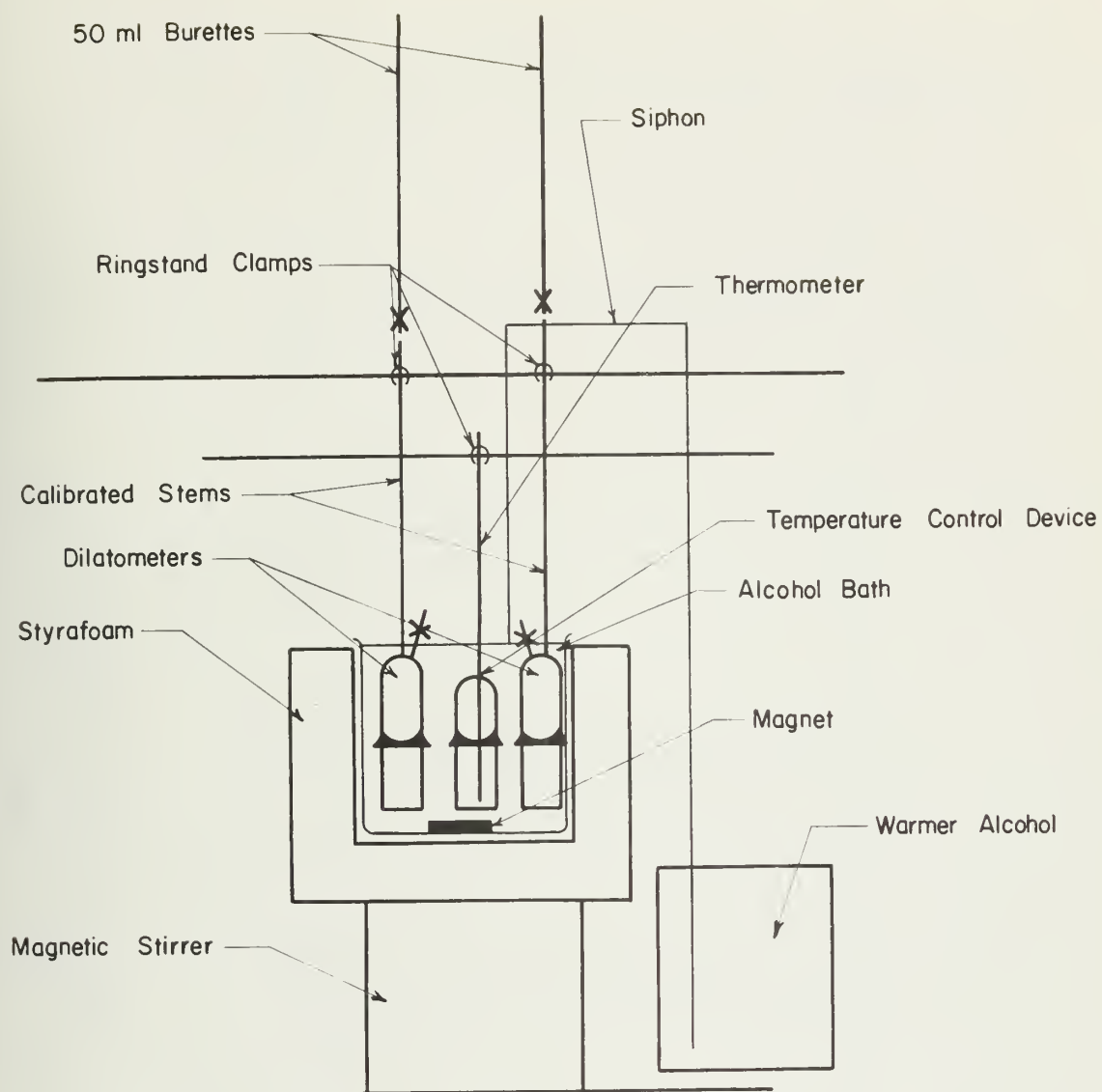


FIGURE 11. SCHEMATIC DIAGRAM OF DILATOMETERS IN OPERATIONAL POSITION.

TABLE 3

DATA FOR THE COMPUTATION OF THE
EXPANSION OF WATER UPON FREEZING

Dilatometer Number	Initial Reading at 1°C, ml	Final Reading at -10°C, ml	Corrected			Expansion For 10 ml, ml	Expansion, ml/ml
			Final Reading ml	Toluene Only Level, ml			
1	-0.512	-0.087	0.425	-0.618	1.043	0.1043	
2	-0.515	-0.090	0.425	-0.616	1.041	0.1041	
1	-0.514	-0.089	0.425	-0.618	1.043	0.1043	
2	-0.513	-0.101	0.412	-0.616	1.028	0.1028	
1	-0.511	-0.093	0.418	-0.618	1.036	0.1036	
2	-0.494	-0.076	0.418	-0.616	1.034	0.1034	
1	-0.525	-0.113	0.412	-0.618	1.030	0.1030	
2	-0.497	-0.067	0.430	-0.616	1.046	0.1046	
Total							0.8301
Average							0.1037
Use							0.104

between the value in the Corrected Final Reading column and the Toluene Only column is equal to the expansion undergone by the distilled water. Since a 10.00 ml quantity of distilled water was used, the total expansion was divided by 10.0 to get the expansion per ml.

A typical calculation to determine the expansion of free water is as follows:

(a) Dilatometer No. 1

63.15 ml of toluene at 1°C = 0.000 ml stem reading

(b) 63.15 ml of toluene at -10°C = -0.735 ml stem reading

(c) 53.15 ml of toluene and 10.0 ml of distilled water at -10°C = 0.418 ml (corrected level)

(d) Since the contraction of toluene is linear, the 53.15 ml of toluene would have contracted to:

$$\frac{53.15}{63.15} \times -0.735 \text{ ml} = -0.618 \text{ ml}$$

(e) Since the corrected final reading was 0.418 ml, the difference, 0.418 ml - (-0.618 ml) = 1.036 ml, which is the expansion due to 10.0 ml of distilled water

(f) $\frac{1.036 \text{ ml}}{10 \text{ ml}} = 0.1036 \text{ ml expansion per ml of distilled water}$

4.2.9 Bound Water Determination

The procedure for determining bound water was essentially identical to the procedure utilized to determine the expansion of distilled water. The 10.0 ml sample of the sludge to be investigated was pipetted into the bottom sections of the dilatometers to which 5 ml of toluene had previously been added. The sample was introduced into the bottom sections below the surface of the toluene. As was pointed out in Section 4.2.6, toluene is slightly soluble in water. The effect of this on the activated sludge was not determined by this author. Introducing the sample below the surface of the toluene was a

measure utilized to prevent the accumulation of air bubbles at the sludge-toluene interface. From this point, the procedure was identical to that used for distilled water expansion in Section 4.2.8. Since the bound water on biological type sludges is thought to be affiliated with the microorganisms present and since the volatile solids are representative of the microorganisms, the weight of the bound water was expressed as a multiple of the weight of volatile solids (BW).

4.2.10 Typical Computation of Bound Water

A typical computation similar to that utilized to determine the bound water as a multiple of volatile solids is as follows:

Assume a 10 ml sample of sludge weighing 9.998 gm and 52.52 ml of toluene are subjected to freezing. Total solids = 0.028 gm and volatile solids = 0.020 gm. Thus, 0.028 gm = dry solids and 9.970 gm = total water.

- (a) 62.52 ml toluene at 1°C = 0.000 ml stem reading
- (b) 62.52 ml toluene at -10°C = -0.733 ml stem reading
- (c) Upon freezing to -10°C the corrected stem reading is 0.386 ml
- (d) The toluene level would be $\frac{52.52}{62.52} \times -0.733 \text{ ml} = -0.616 \text{ ml}$
- (e) The difference due to water ice expansion = 0.386 ml - (-0.616 ml) = 1.002 ml
- (f) Since 1.00 ml of distilled water expands 0.104 ml upon freezing 1.002 ml represents

$$\frac{1.002 \text{ ml}}{.104 \text{ ml/ml}} = 9.64 \text{ ml free water}$$

- (g) Total water - free water = bound water 9.97 ml - 9.64 ml = 0.33 ml = 0.33 gm
- (h) Bound Water Multiple (of volatile solids) = $\frac{.33 \text{ gm bound water}}{0.020 \text{ gm volatile solids}} = 16.5$

4.3 Total Solids Determination

The total solids determination was similar to that described in Standard Methods (1965). The exception to the technique presented in Standard Methods (1965) is that an aluminum dish was used instead of the porcelain container.

4.4 Suspended Solids and Volatile Solids Determinations

Except for the use of a glass fiber filter mat* rather than an asbestos mat, the method utilized for the determination of volatile and suspended solids was identical to the technique described in Standard Methods (1965). The technique for the determination of volatile and suspended solids using glass fiber filters was described by Dick (1965). He utilized the glass fiber filter instead of the customary asbestos pad or membrane filter and found that the glass fiber filters were equal or superior to the other methods listed in accuracy, reliability and convenience. The glass fiber filters were more economical than the two other techniques also. Due to the hydroscopic character of the Gooch crucibles, individual desiccators, as advocated by Winneberger, Austin and Klett (1963), were used to avoid weight changes during the repeated openings of a conventional desiccator. The desiccators consisted of an 8-oz wide mouth, screw-cap bottles containing about 20 gm of silica gel and a 2-oz bottle to hold the crucible above the desiccant. An oven time of approximately 5 hours was used for drying and approximately 3 hours was used for cooling in the desiccator prior to the final weighing.

*Glass fiber filters manufactured by Hurlbut Paper Company, Glifton, New Jersey No. 934-HH 21 mm diameter.

4.5 Sludge Index Determination

One of the primary objectives of this research was to determine whether ultrasonic vibrations would decrease the bound water multiple as well as increase the settled sludge concentration. It was considered desirable to be able to compare the bound water multiple with the sludge volume index as did Heukelekian and Weisburg (1956) rather than to only the compacted sludge concentration or settled sludge height. The sludge index (SI) determination was initiated for use in this research to replace the sludge volume index since the SVI required the use of a 1000 ml graduated cylinder rather than a 3.5 inch diameter plexiglass column.

The sludge index was defined to be as similar as possible to the sludge volume index as given in Standard Methods (1965). Specifically, the difference between the two is that the sludge volume index requires a 1000 ml graduated cylinder whereas the sludge index utilizes a 1.5 ft column with a volume of 2.850 ml. The sludge index was determined by allowing the activated sludge, the sludge previously exposed to the ultrasonic vibrations or the unexposed control, to settle for 30 minutes. The volume occupied by the activated sludge at the end of the 30 min settling period was expressed as a percentage of the entire volume. Finally, the activated sludge in the column was thoroughly mixed and a sample was taken for suspended solids analysis. This was expressed as a percent by weight. The sludge index was determined by the expression:

$$\text{Sludge index} = \frac{\text{percent settled by volume}}{\text{percent suspended matter}}. \quad (6)$$

4.6 Measurement of Temperature

Due to the nature of the bound water determination, an accurate measurement of temperature was essential. Heukelekian and Weisburg (1956) utilized a mercury type thermometer calibrated to 0.10°C . Jones and Gortner (1927) utilized a 0°C to -65°C pentane thermometer which was calibrated to 0.10°C . The thermometer used by Fisher (1936) was also calibrated to 0.10°C . Since the thermometer calibrated to 0.10°C and having the required range was not available at the time of this research, a thermometer with a calibration of 1°C was used. To insure that this thermometer provided sufficient accuracy, a toluene contraction curve such as that described in Section 3.2.6 was experimentally determined. The plotted points of Figures 7 and 8 were achieved by noting the level of toluene in the calibrated stem at approximately every odd numbered degree level while lowering the temperature and at approximately every even numbered degree level while raising the temperature to its original level. As can be seen on Figures 7 and 8, the toluene levels fall essentially on a straight line. This indicates that with sufficient time taken for reaching equilibrium conditions, the thermometer utilized in this research provided sufficient accuracy.

4.7 Determination of Settling Velocity

The settling velocity of the sludge-water interface was determined by measuring the slope of the straight line, zone settling, portion of the sludge height vs time of settling curve, as illustrated in Figure 3.

CHAPTER 5. DISCUSSION OF RESULTS

5.1 Introduction

As the reader follows through this chapter, he will note that the burden of the explanation of the results of this study is placed upon the physical conditions of the particular sludge in question. Since the two Champaign-Urbana sludges were from the same facility, the only differences between them, which the author can ascertain, were the additional nine hours of aeration given to the Champaign-Urbana Aerated Return Sludge and the higher suspended solids concentration of this sludge. Therefore, the only apparent difference between the Champaign-Urbana Activated Sludge after nine hours of aeration during laboratory study and Champaign-Urbana Aerated Return Sludge brought directly from the sewage treatment plant to the laboratory was the concentration. Since Lyon (1952) and Schulte (1964) both obtained improvements in settleability from exposing an activated sludge and a return activated sludge to ultrasonic vibration, the author did not consider the difference in the concentration of the two Champaign-Urbana sludges responsible for the difference in the results as described in the following Sections 5.2, 5.3, 5.4, 5.5.

As described in the above-mentioned sections, the physical condition of the sludges was discussed as being of importance primarily for the changes brought about by the ultrasonic vibrations.

5.2 The Effects of Ultrasonic Vibrations on the Sludge Index of Activated Sludge

5.2.1 General

The three experimental variables, which were described in Chapter 2, are discussed relative to their effect on the ratio, SI_s/SI_c , in Sections 5.2.2,

5.2.3 and 5.2.4. This ratio, which is the sludge index of the sample exposed to the ultrasonic vibrations (SI_s) divided by the sludge index of the control (SI_c), was adopted to prevent any natural change in the sludge from affecting the final results. This is based on the premise that a natural change would occur in both the exposed sample and the control; thus, both would be cancelled.

5.2.2 Power Applied

In order to study the importance of the power applied, the frequency of vibration was kept constant at 18.5 kc/sec while the power applied was varied from 25 watts to 50 watts to 75 watts. This same procedure was utilized whenever the effect of power applied was studied.

5.2.2.1 Champaign-Urbana (C-U) Activated Sludge

The application of higher power levels to Champaign-Urbana activated sludge, which was described in Appendix A, did not provide the reduction in SI_s/SI_c as was anticipated. The only significant reduction in SI_s/SI_c , as can be seen in Figure 12, was caused by the lowest power application. The fact that C-U activated sludge had excellent settling characteristics prior to this experimentation may offer an explanation of these surprising results. Bacterial cells in a sludge with excellent settling properties have been shown to exhibit adhesive properties due to considerable amounts of intracellular poly-beta-hydroxybutyric acid (PHB) (Crabtree, et al., 1966). The author suggests that the bubbles formed during the cavitation which were caused by the ultrasonic vibrations became attached to these adhesive cells. It was assumed that dissolved gases entered the cavities when a vacuum existed therein, thus creating a bubble. These bubbles were also observed by Schulte (1964). This apparently buoyed up the cells and prevented them from settling as rapidly

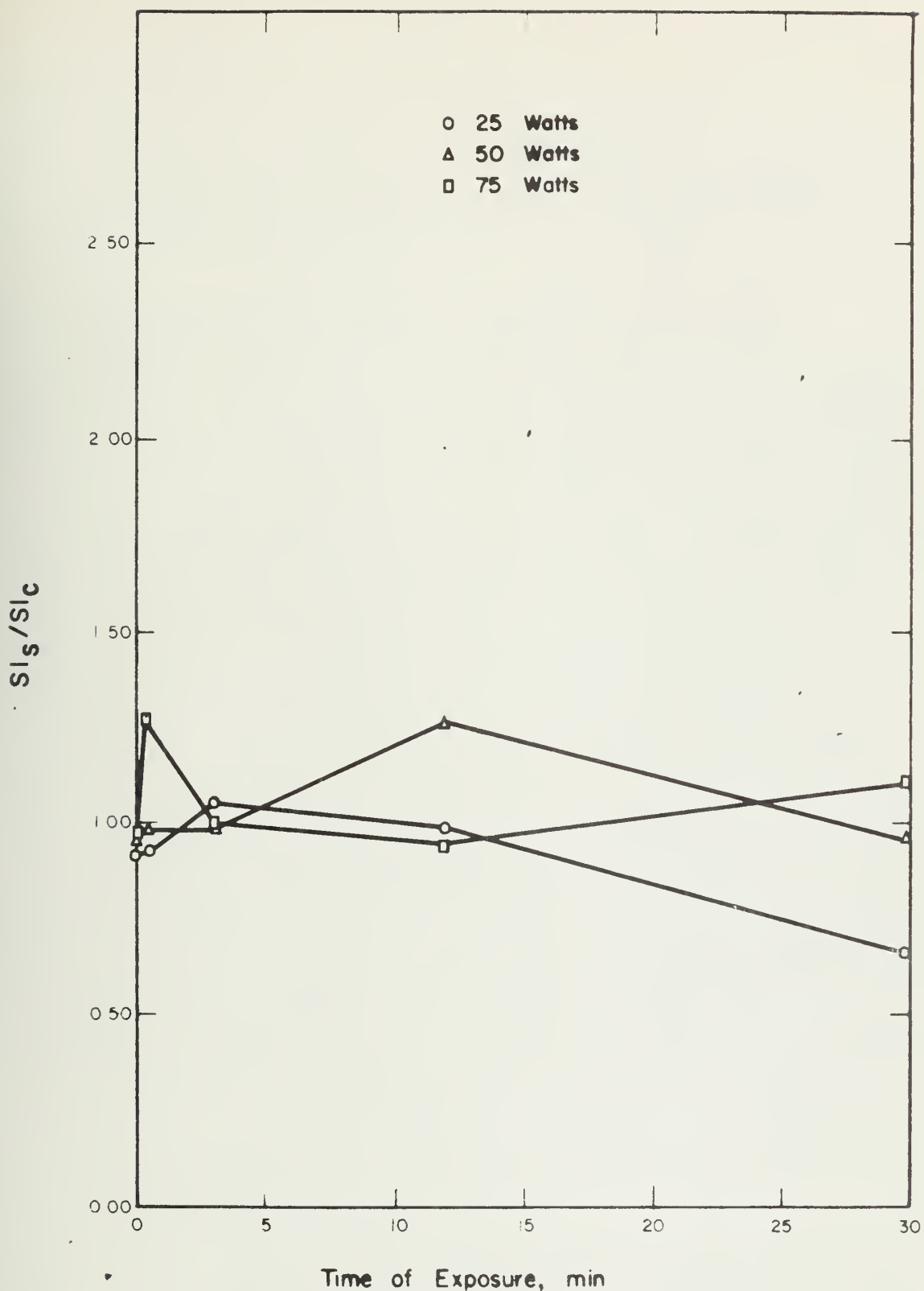


FIGURE 12. CHAMPAIGN - URBANA ACTIVATED SLUDGE SI_S/SI_C VS TIME OF EXPOSURE AT 18.5 KC/SEC.

as they normally would. Since cavitation occurred only slightly during exposure to 25 watts, few bubbles were formed; therefore, SI_s/SI_c , for 25 watts of power application, generally decreased. The cause of this decrease will be discussed in Section 5.5.2.

5.2.2.2 Champaign-Urbana Aerated Return Sludge

Contrary to the above discussion, increased power levels did result in decreased values of SI_s/SI_c for Champaign-Urbana aerated return sludge. This sludge is described in Appendix A. The author cannot offer an explanation as to why a power application of 50 watts proved to be more beneficial in reducing SI_s/SI_c than a power application of 75 watts, as illustrated in Figure 13. Since this sludge was approaching the endogenous state when removed from the sewage treatment plant, the PHB was probably present in smaller quantities. Because of this the bubbles possibly did not become attached to the microorganisms so readily, and the settling of the sludge was not affected. The suggested cause of the improved settleability is that the ultrasonic agitation created the possibility of greater contacts thereby promoting flocculation to a greater extent. For reasons discussed in Section 5.5.2, shaking loose of capsular material was excluded as a possible cause of the improved settleability for this particular sludge. This flocculation apparently resulted in tougher floc particles which were able to withstand their transfer to the settling column without breakup.

5.2.2.3 Sullivan Activated Sludge

High power applications produced significant reductions in SI_s/SI_c for a filamentous type bulking sludge such as the Sullivan Activated Sludge, as shown in Figure 14. This filamentous sludge was probably lacking in PHB

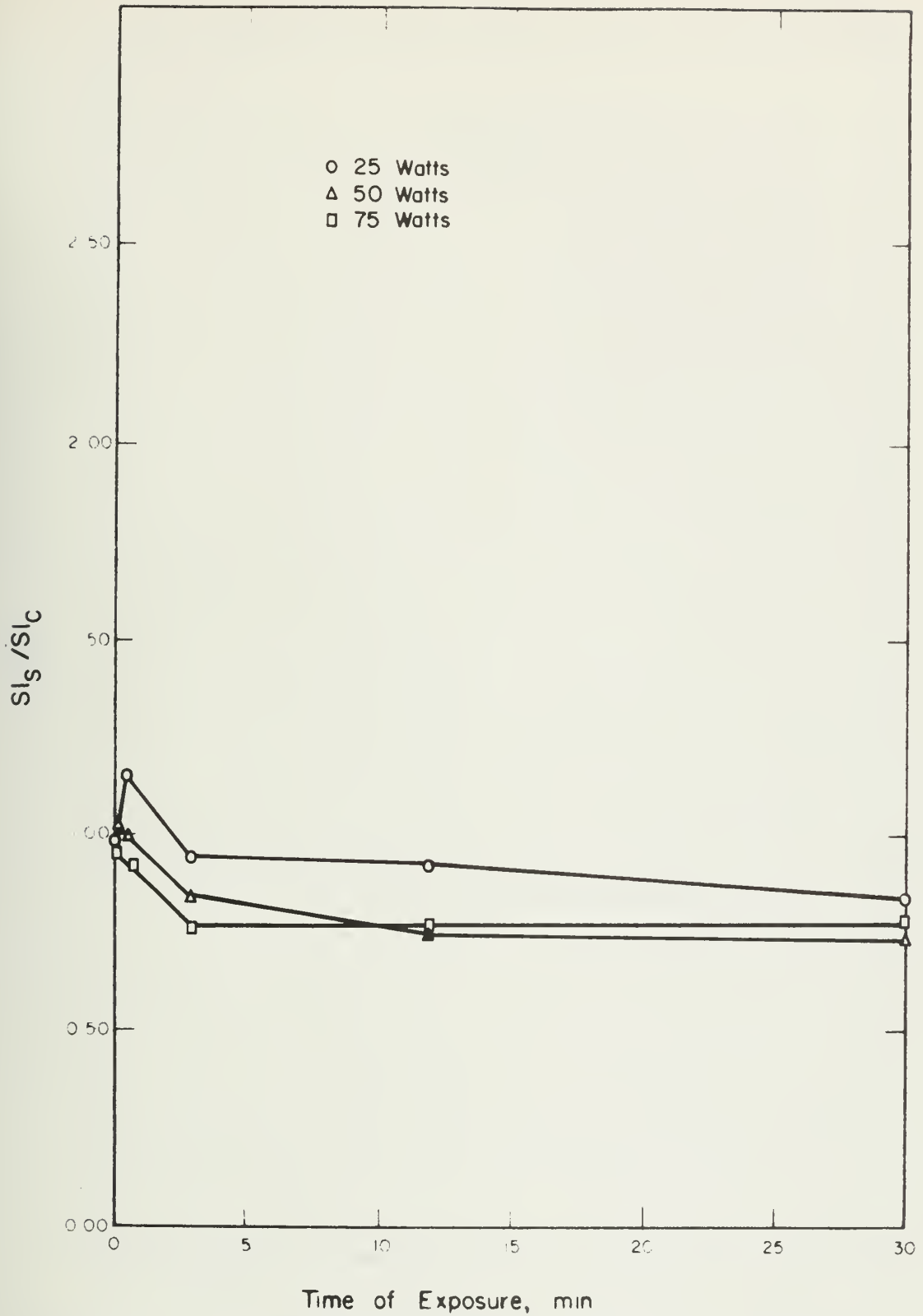


FIGURE 13. CHAMPAIGN - URBANA AERATED RETURN SLUDGE SI_S / SI_C VS TIME OF EXPOSURE AT 18.5 KC/SEC.

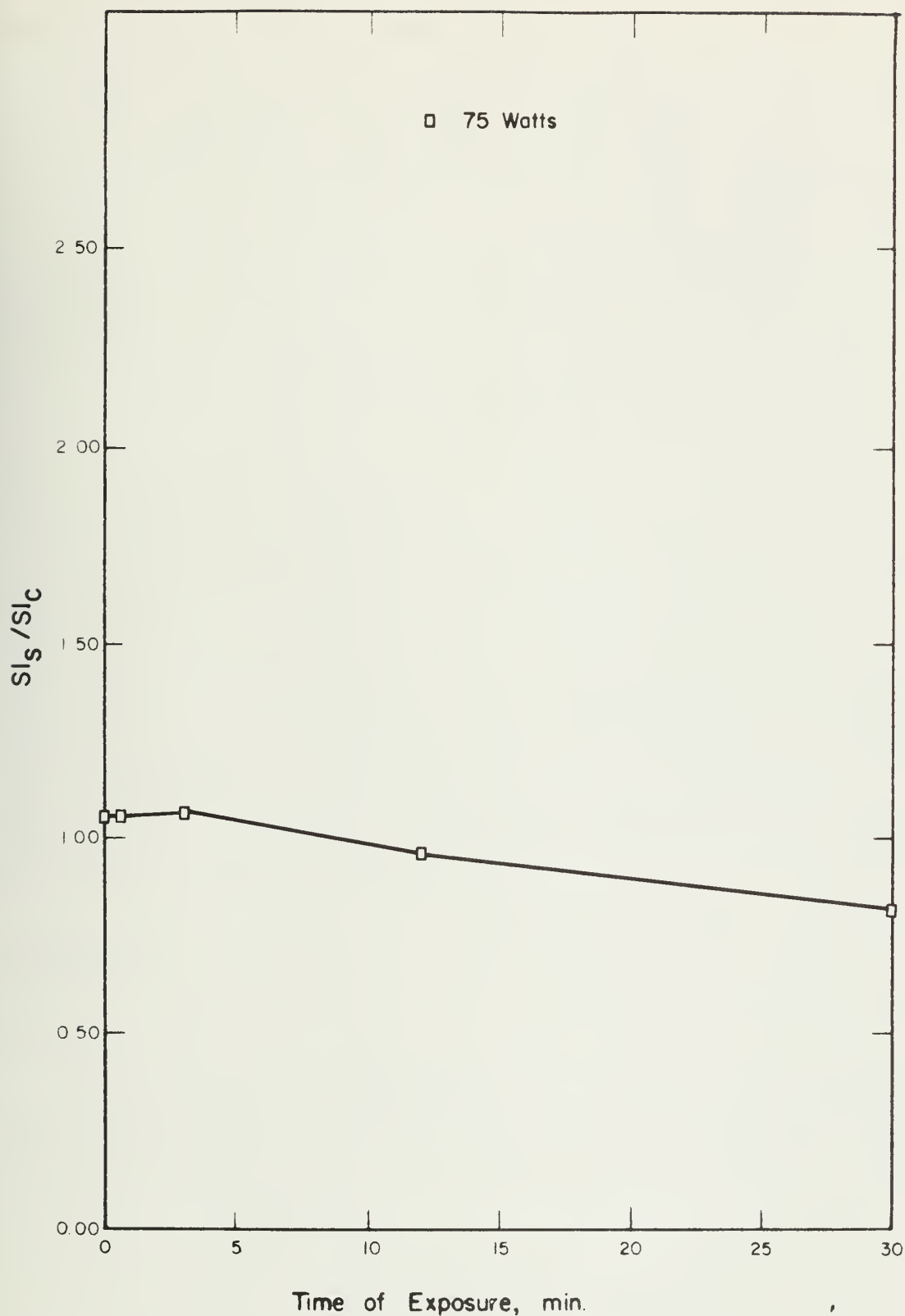


FIGURE 14. SULLIVAN ACTIVATED SLUDGE SI_S / SI_C
VS TIME OF EXPOSURE AT 18.5 KC/SEC.

as indicated by the fact that the bubbles did not adhere to and buoy up the settling sludge. The entrapment of bubbles by agglomerated filaments did not appear to be significant. According to Walters (1966) activated sludges, which are acclimated to high chemical oxygen demand (COD) to Nitrogen (N) ratios, $(\text{COD/N}) = 56.0$, do not accumulate PHB while carbohydrate accumulation is maintained at the same level as for an activated sludge acclimated to a COD/N ratio of 31.4. Possibly, the ultrasonic agitation increased the opportunity for contact as well as removed polysaccharide capsular material therefore promoting flocculation of the floc particles. This flocculation apparently resulted in a tougher floc which was able to withstand being transferred into the settling column. Therefore, the improved settleability, as shown in Figure 14, was perhaps due partially to the flocculation and partially due to the reason described below. Since this sludge was exposed to high concentrations of carbohydrates (see Appendix A), an excessive amount of capsular material could have been present on the outer surface of the bacterial cell wall. The effect of removing this capsular material on improved settleability will be discussed in Section 5.5.2.

5.2.3 Frequency

5.2.3.1 General

In order to study the importance of the frequency of vibration, the power applied was kept constant while varying the frequency from 18.5 kc/sec to 32 kc/sec to 45.0 kc/sec.

5.2.3.2 Champaign-Urbana Activated Sludge

Frequency appeared to be quite significant when experimenting with

this sludge as shown in Figure 15. As was theoretically predicted, the lower frequency vibrations were probably absorbed less in the medium and reached the contents of the exposure column more completely. The author cannot explain the increase in SI_s/SI_c for the sample exposed to a frequency of 4.50 kc/sec nor can it be explained why SI_s/SI_c for the sample exposed to 32.5 kc/sec increased greatly and then underwent a rapid decrease. The author describes the mechanism thought to be partially responsible for improving the settleability in Section 5.4.2 in addition to the improved flocculation resulting from increased contact.

5.2.3.3 Champaign-Urbana Aerated Return Sludge

Frequency proved to be a relatively unimportant variable when experimenting with this particular sludge, as shown in Figure 16. Generally, there was a decrease in SI_s/SI_c as the time of exposure increased. This was expected although no significant differences were noted between the samples exposed to the various frequencies. The author is unable to describe why SI_s/SI_c for the sample exposed to 32.5 kc/sec dipped below that of the sample exposed to 18.5 kc/sec between the exposure times of 3 to 20 min. As mentioned in Section 5.2.2.1, few bubbles were formed at a power input of 25 watts. This was the power applied to the sludge for the studies illustrated in Figure 16. The importance of the lower frequencies can also be seen in Figure 16. The lower frequencies vibrations were apparently not absorbed to the extent that the 45 kc/sec vibrations were. Therefore, the capsular and other materials were not agitated loose from the microorganisms in the sludge to the extent that they were when exposed to lower frequencies. The importance of this fact is brought out in Section 5.4.2.

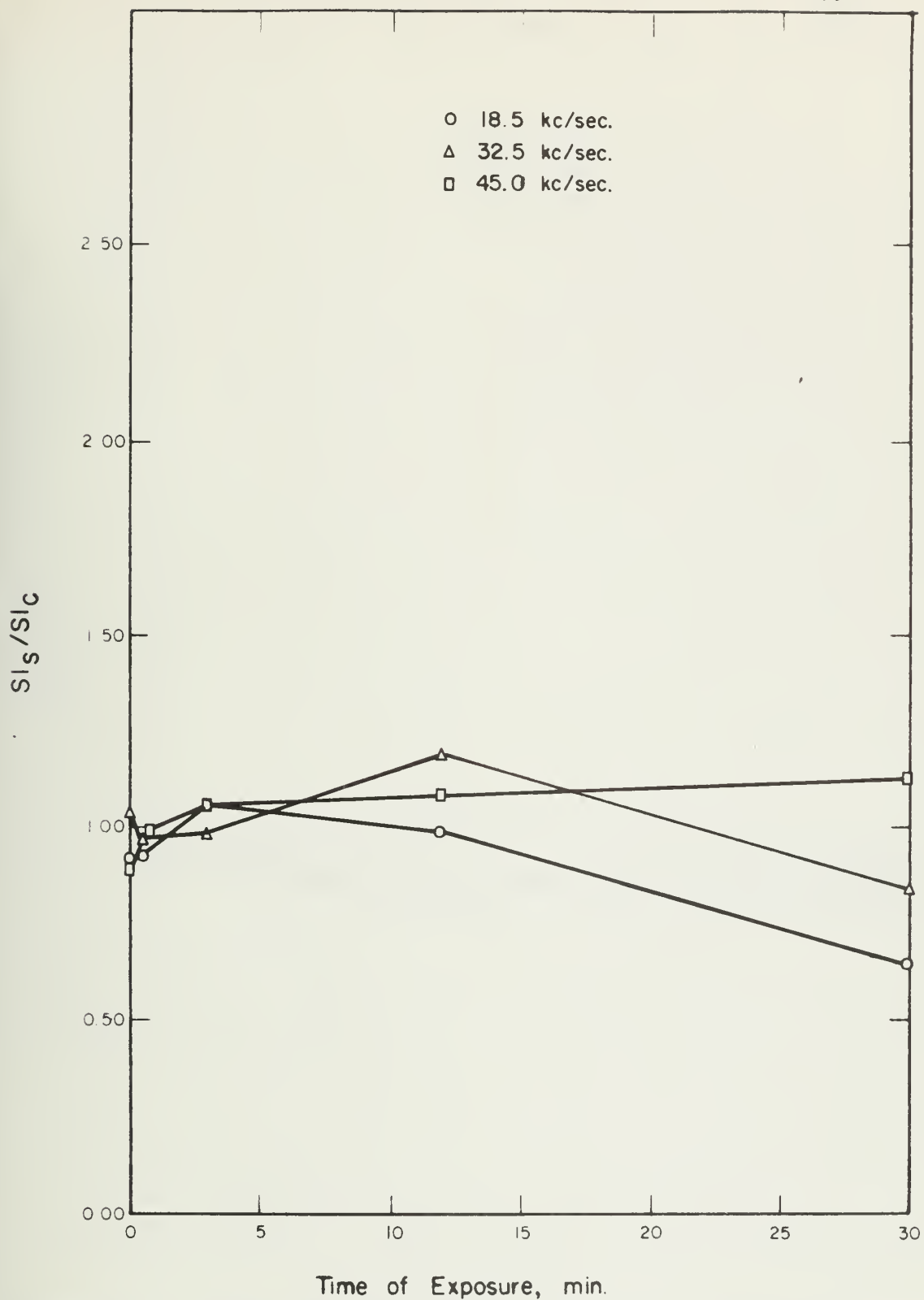


FIGURE 15. CHAMPAIGN - URBANA ACTIVATED SLUDGE SI_S/SI_C VS TIME OF EXPOSURE AT 25 WATTS.

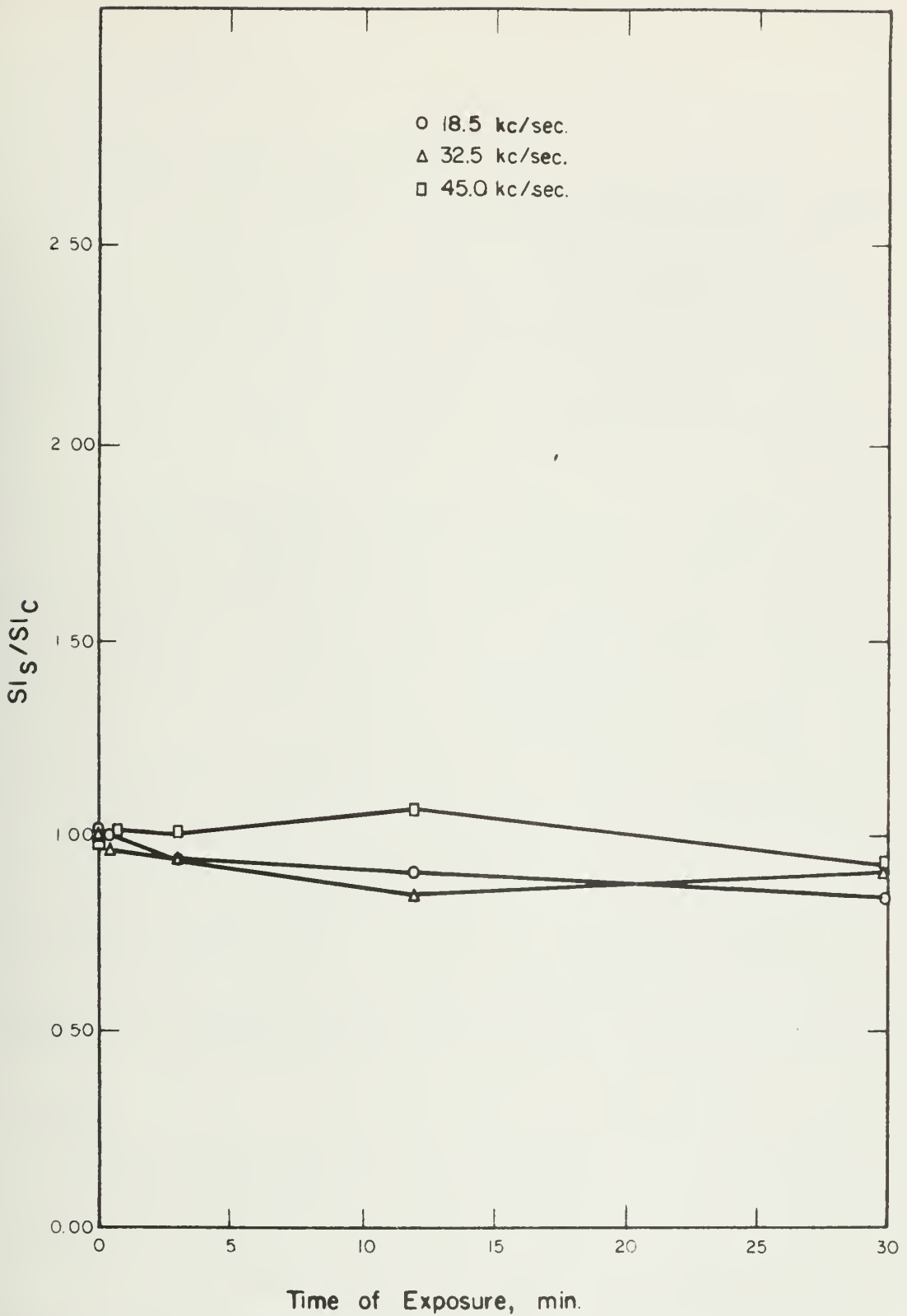


FIGURE 16. CHAMPAIGN - URBANA AERATED RETURN
SLUDGE Sl_s/Sl_c VS TIME OF EXPOSURE
AT 25 WATTS.

5.2.4 Time of Irradiation

5.2.4.1 Champaign-Urbana Activated Sludge

No definite trend was established with increased time of exposure, as can be seen in Figures 12 and 15. Thirty minutes of exposure greatly reduced SI_s/SI_c for the sample exposed to the least power input, 25 watts, and the lowest frequency, 18.5 kc/sec. The other combinations of power and frequency produced negligible or negative results after 30 min exposure.

5.2.4.2 Champaign-Urbana Aerated Return Sludge

For the lower frequencies, 32.5 kc/sec and 18.5 kc/sec, generally the trends established during the first 10 min of exposure are continued, as can be seen in Figures 13 and 16. Only on the sample exposed to the highest frequency, 45.0 kc/sec, did SI_s/SI_c fail to decrease.

5.2.4.3 Sullivan Activated Sludge

As can be seen in Figure 14, after the first 3 min of SI_s/SI_c increase, the ratio decreased with increased time of exposure as was expected from theoretical considerations.

5.3 The Effects of Ultrasonic Vibrations on Settling Velocity of Activated Sludge

5.3.1 General

The three experimental variables, which were described in Chapter 2, are discussed relative to their effect on the ratio, V_s/V_c , in Sections 5.3.2, 5.3.3 and 5.3.4. This ratio, which is the settling velocity of the sludge-water interface of the sample exposed to the ultrasonic vibrations (V_s) divided by the settling velocity of the sludge-water interface of the

control (V_c), was adopted to prevent any natural change in the sludge from affecting the results. This is based on the premise that a natural change would occur in both the exposed sample and the control and would be cancelled.

This subchapter dealing with sludge settling velocity is governed by the same factors as was the preceding subchapter, 5.2.0; therefore, the discussion of the results will be presented only by the corresponding section in the previous subchapter, 5.2.

5.3.2 Power Applied

The conditions under which power applications were studied have been previously discussed in Section 5.2.2.

5.3.2.1 Champaign-Urbana Activated Sludge

High power applications on this sludge did not produce the anticipated increase in V_s/V_c as shown in Figure 17. These results are understandably comparable to the SI_s/SI_c ratio described in Section 5.2.2.1.

5.3.2.2 Champaign-Urbana Aerated Return Sludge

As was discussed in Section 5.2.2.2 relative to SI_s/SI_c , ultrasonic vibrations produced an increase in V_s/V_c as can be seen in Figure 18. This is understandable since an increase in settling rate would cause a reduction in the sludge index.

5.3.2.3 Sullivan Activated Sludge

Also, as for the Champaign-Urbana Aerated Return Sludge, the increased power application produced significant increases in the ratio, V_s/V_c , as can be seen in Figure 19. This also parallels the results described in 5.2.2.3

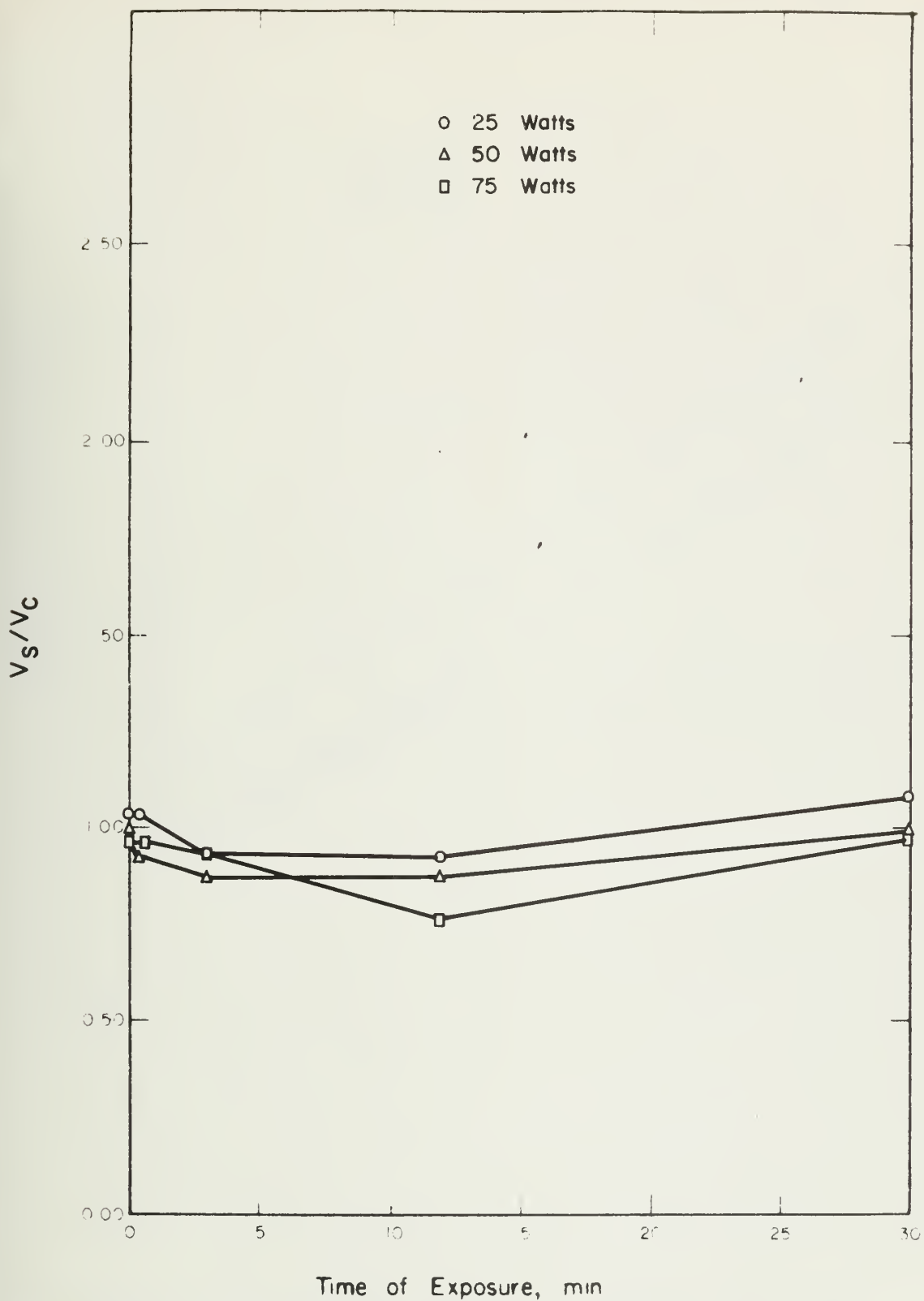


FIGURE 17. CHAMPAIGN - URBANA ACTIVATED SLUDGE V_S/V_C VS TIME OF EXPOSURE AT 18.5 KC/SEC.

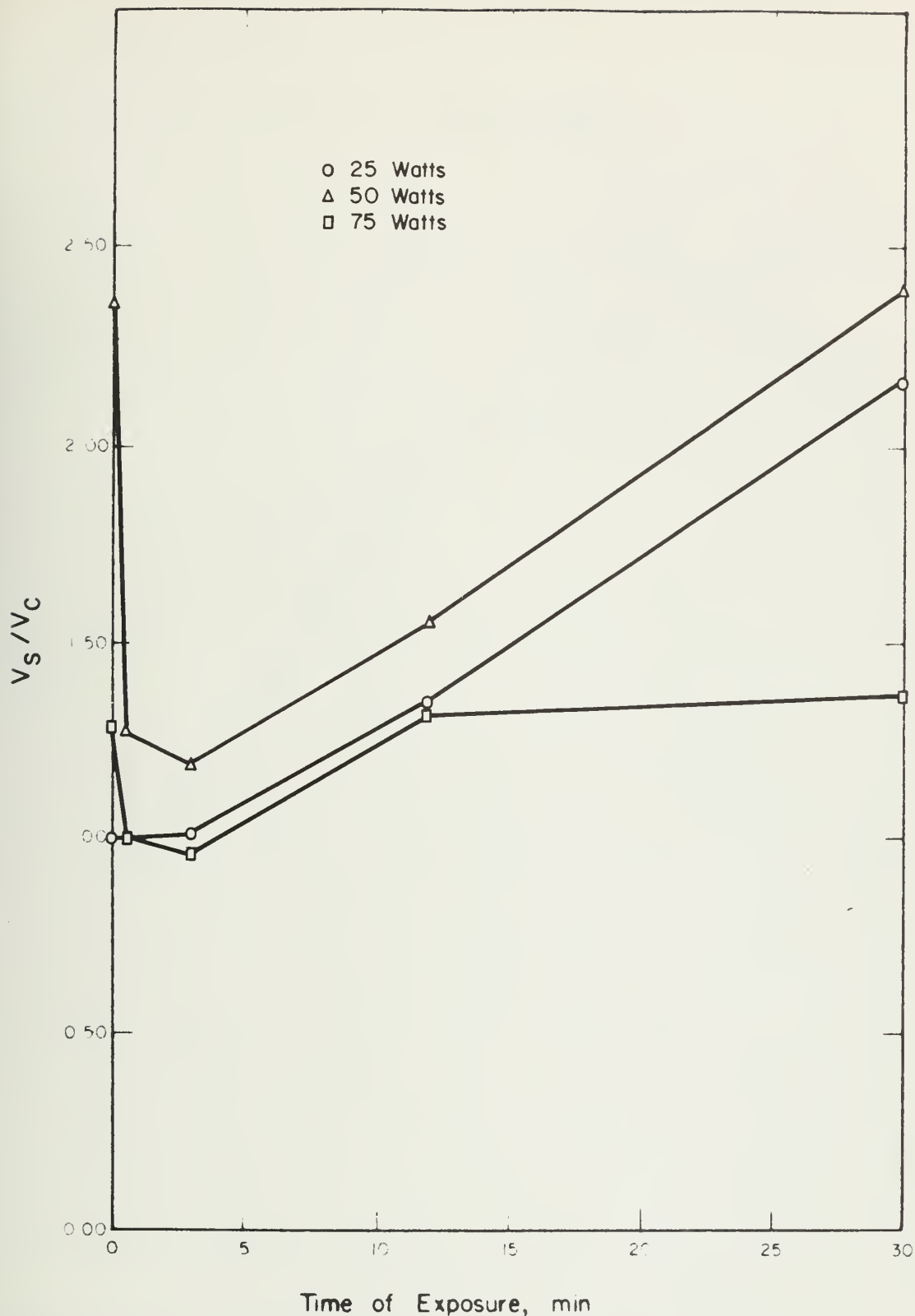


FIGURE 18. CHAMPAIGN - URBANA AERATED RETURN
SLUDGE V_S/V_C VS TIME OF EXPOSURE
AT 18.5 KC/SEC.

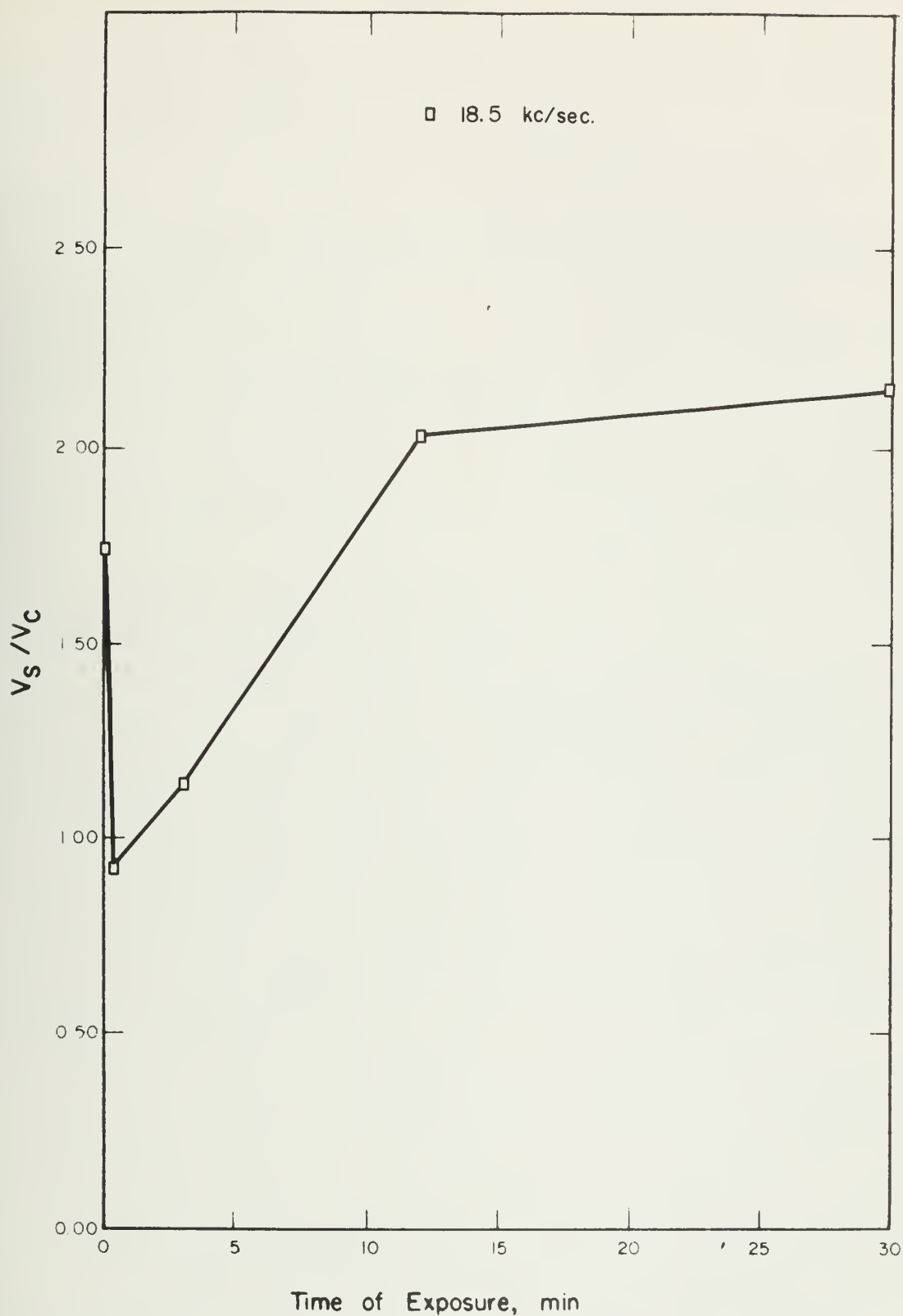


FIGURE 19. SULLIVAN ACTIVATED SLUDGE V_S/V_C
VS TIME OF EXPOSURE AT 75 WATTS.

in which increased power applications with ultrasonic vibrations produced significant reductions in SI_s/SI_c .

5.3.3 Frequency

The conditions under which frequency vibration was studied were described in Section 5.2.3.2.

5.3.3.1 Champaign-Urbana Aerated Return Sludge

Frequency appeared to be a relatively unimportant variable when Champaign-Urbana Activated Sludge is being studied. This can be seen in Figure 20.

5.3.3.2 Champaign-Urbana Aerated Return Sludge

The significance of frequency as a variable in ultrasonic vibration is apparent in Figure 21. The lowest frequency (18.5 kc/sec) vibrations produced the most improved settling rate, while little or no improvement was achieved using the two higher frequencies.

5.3.4 Time of Irradiation

Increased time of exposure to have amplified the changes produces by shorter periods of exposure.

5.4 The Effects of Ultrasonic Vibrations on the Total Solids in the Supernatant

5.4.1 General

A study of the beneficial effects of ultrasonic vibrations without considering the secondary effects would not be complete. As has been reported earlier, an increase in the total solids in the supernatant occurred when Schulte (1964) exposed a sample of activated sludge to ultrasonic vibrations.

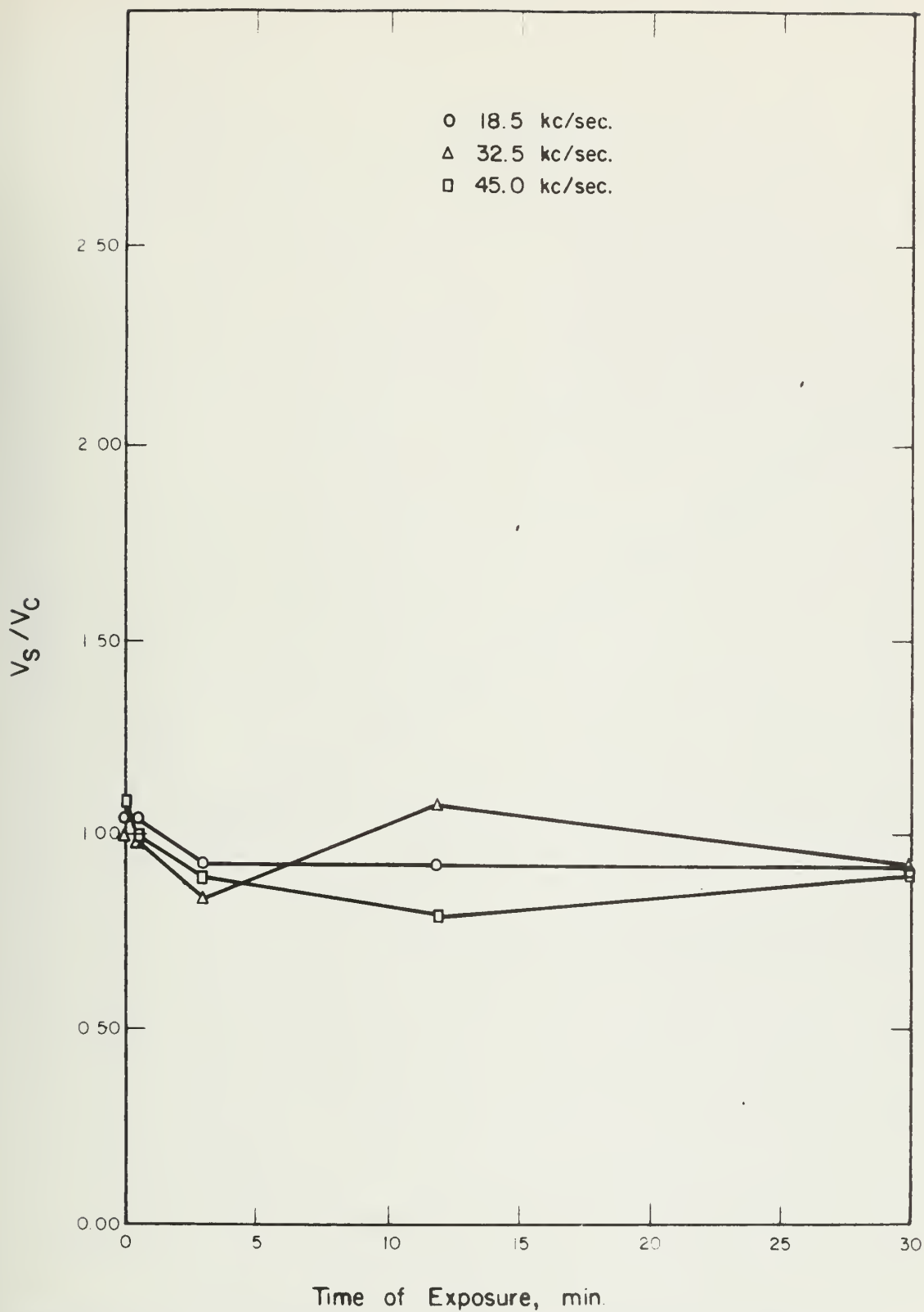


FIGURE 20. CHAMPAIGN - URBANA ACTIVATED SLUDGE V_S/V_C VS TIME OF EXPOSURE AT 25 WATTS.

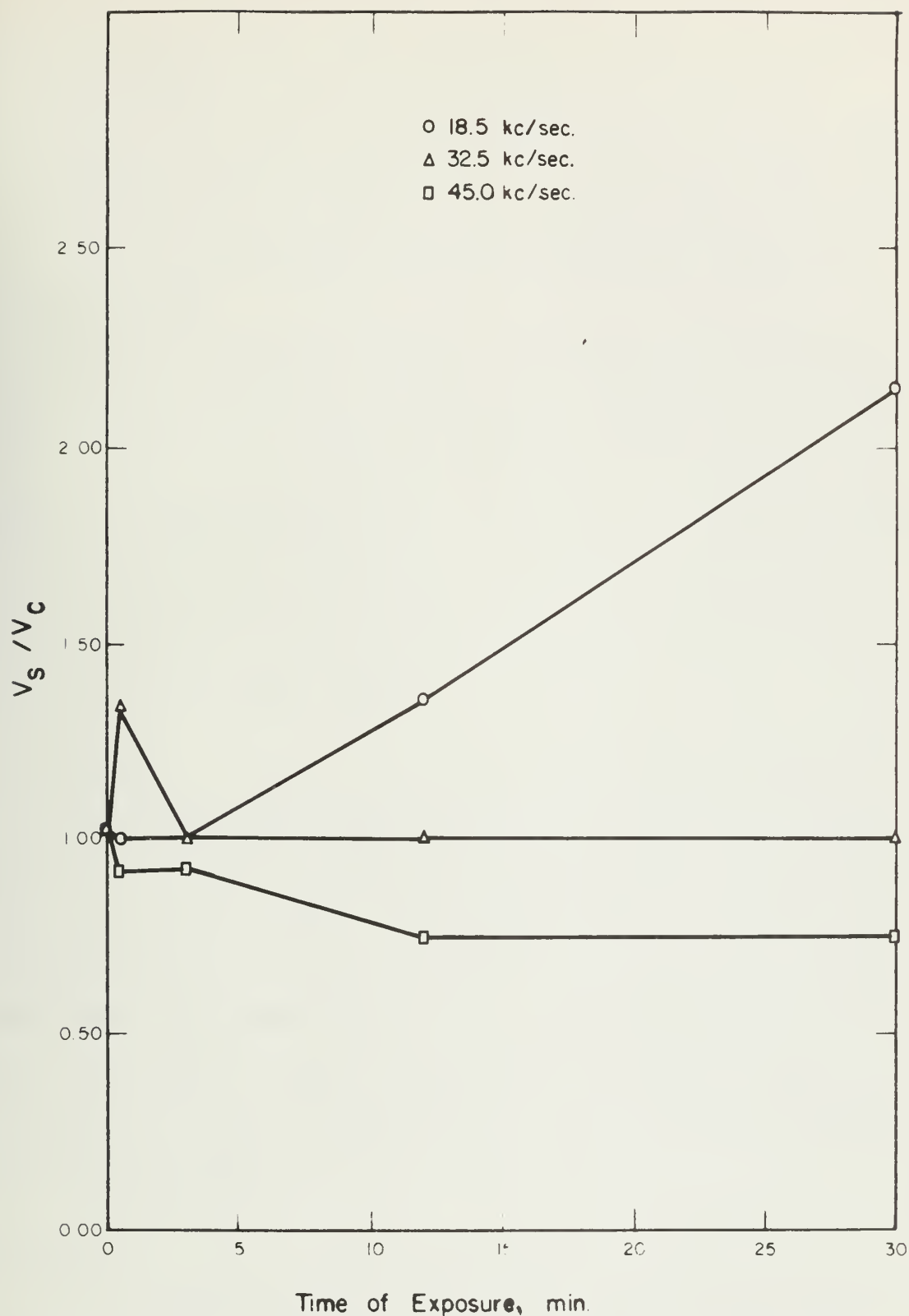


FIGURE 21. CHAMPAIGN - URBANA AERATED RETURN
SLUDGE V_S / V_C VS TIME OF EXPOSURE
AT 25 WATTS.

The agitation produced in the sludge suspension by ultrasonic vibration probably shook colloidal and insoluble solids, such as polysaccharide capsular material, off the microorganisms as well as lysing (Alliger, 1963) some of them. Shaking insoluble polysaccharide capsular material off the microorganisms has been accomplished by Heym (1964) and has been attempted by Crabtree et al. (1966).

The three experimental variables, which were discussed in Chapter 2, are further discussed in this section. They are discussed relative to their affect on the ratio, TS_s/TS_c . This ratio, which is the total solids in the supernatant of the sample exposed to the ultrasonic vibrations (TS_s) divided by the total solids in the supernatant of the sample used as the control (TS_c), was utilized to prevent any natural change in the sludge characteristics from affecting the final results.

5.4.2 Power Applied

The conditions under which power applications were studied have been previously discussed in Section 5.2.2. As can be seen in Figures 22, 23, and 24, for all three sludges, there was a greater rise in TS_s/TS_c for the samples exposed to the higher power inputs. This supports the studies of Hermans (1938) showing that as the power applied to the transducer was increased, the agitation produced in the medium was increased. Therefore, the capsular and other material adhering to the floc particles were shaken off into the liquid medium.

5.4.3 Frequency

The conditions under which frequency vibration was studied were described in Section 5.2.3.2.

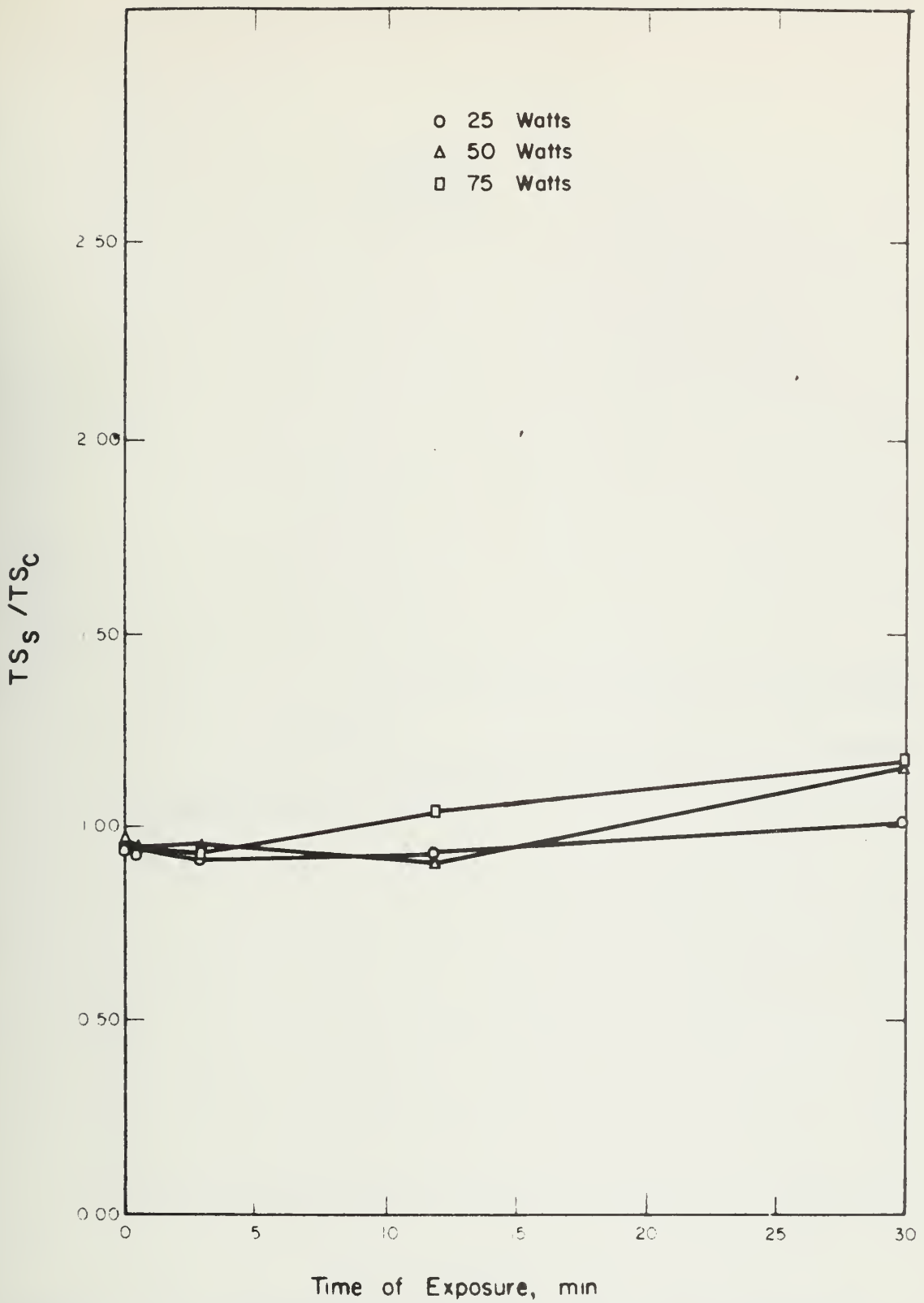


FIGURE 22. CHAMPAIGN - URBANA, ACTIVATED SLUDGE TS_s / TS_c VS TIME OF EXPOSURE AT 18.5 KC/SEC.

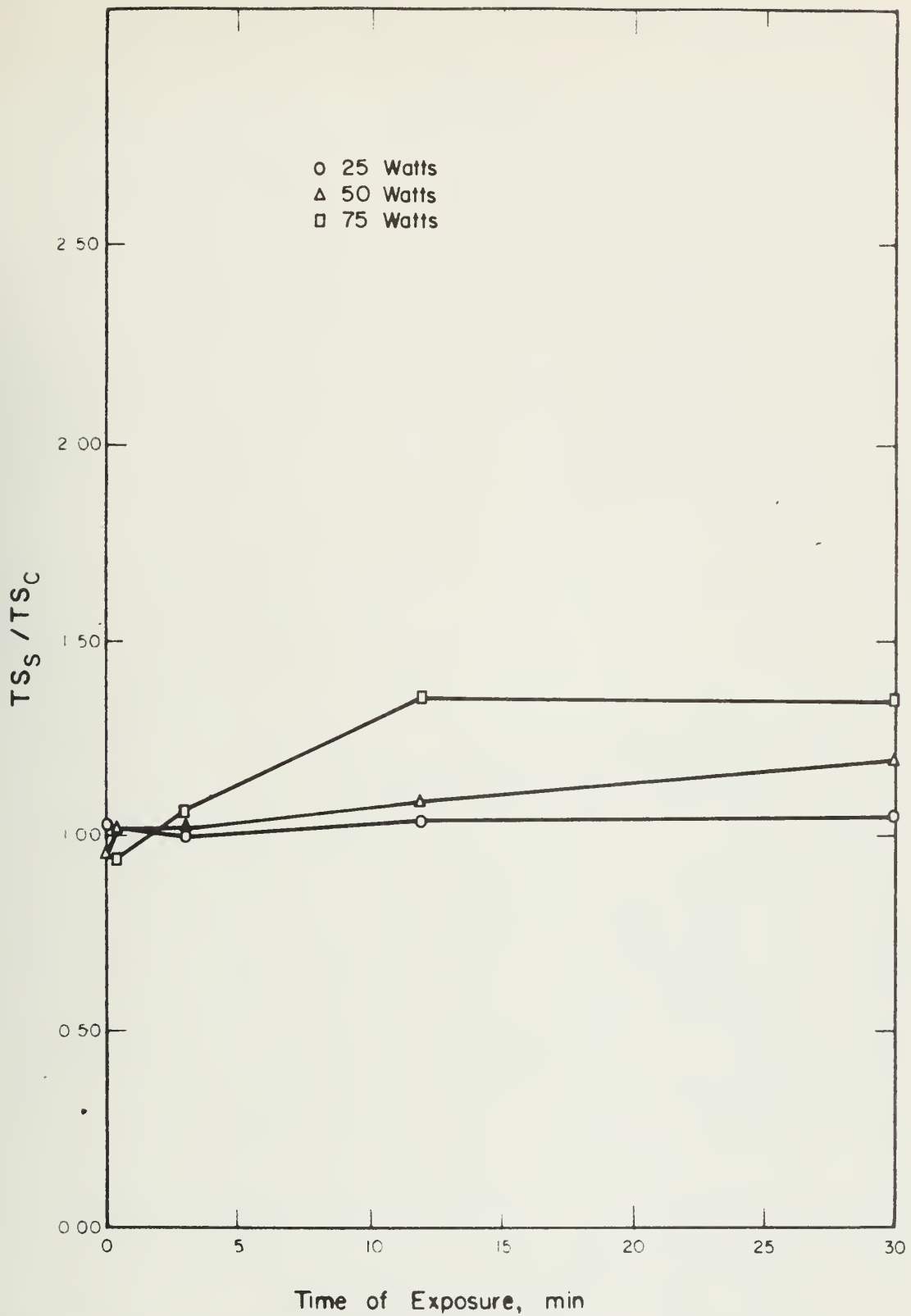


FIGURE 23. CHAMPAIGN - URBANA AERATED RETURN
SLUDGE TS_s/TS_C VS TIME OF EXPOSURE
AT 18.5 KC/SEC.

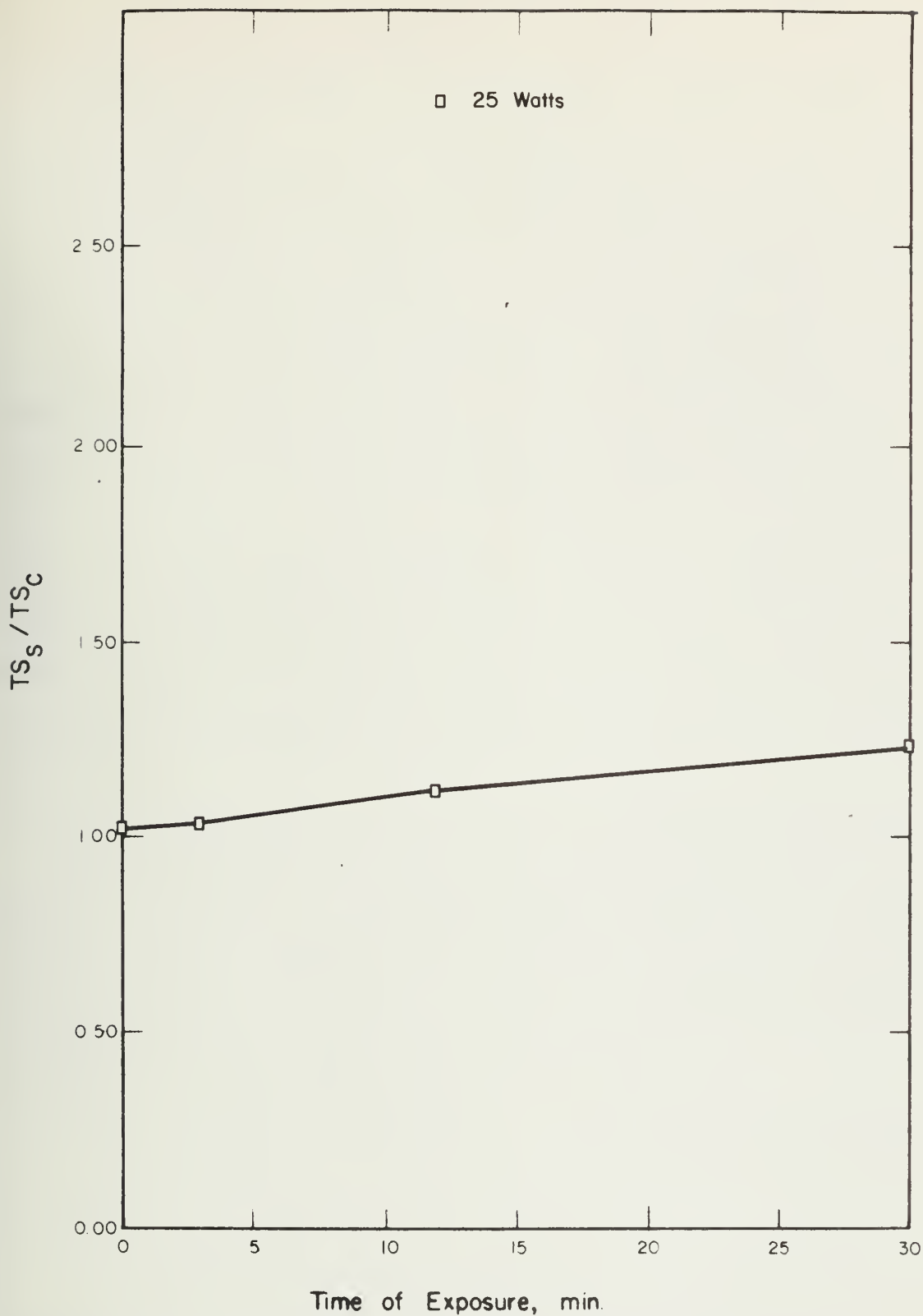


FIGURE 24. SULLIVAN ACTIVATED SLUDGE TS_s / TS_C
VS TIME OF EXPOSURE AT 18.5 KC/SEC.

Frequency did not appear to be significant in regard to total solids in the supernatant, as can be seen in Figures 25 and 26. There is one exception in Figure 26; TS_s/TS_c of the sludge exposed to an ultrasonic power input of 25 watts and a frequency of 32.5 kc/sec increased substantially over TS_s/TS_c of the same sludge exposed to the same power application but with a higher and a lower frequency of vibration. The author cannot explain this exception. In Figure 25, it would appear that some type of material was being agitated loose from the sludge organism since the three curves indicate slight increases in TS_s/TS_c . The ratio, TS_s/TS_c , of the Champaign-Urbana Activated Sludge, which was exposed to a frequency of 18.5 kc/sec, rose gradually; whereas, the other two samples rose abruptly and remained relatively constant. The fact that all three TS_s/TS_c curves increased upon continued exposure is significant. See Section 5.5.2 for further discussion.

5.4.4 Time of Exposure

One can conclude from Sections 5.4.2 and 5.4.3 that, generally, trends, either an increase or a decrease in TS_s/TS_c , established after the first several minutes of exposure to the ultrasonic vibrations were continued upon further exposure. The results were irregular initially and no definite trends were observed during the first several minutes.

5.5 The Effects of Ultrasonic Vibrations on the Bound Water of Activated Sludge

5.5.1 General

The utilization of ultrasonic vibrations to remove the bound water of activated sludge has never, to the author's knowledge, been attempted. The theory on which this study was based was discussed in Section 4.2.1.

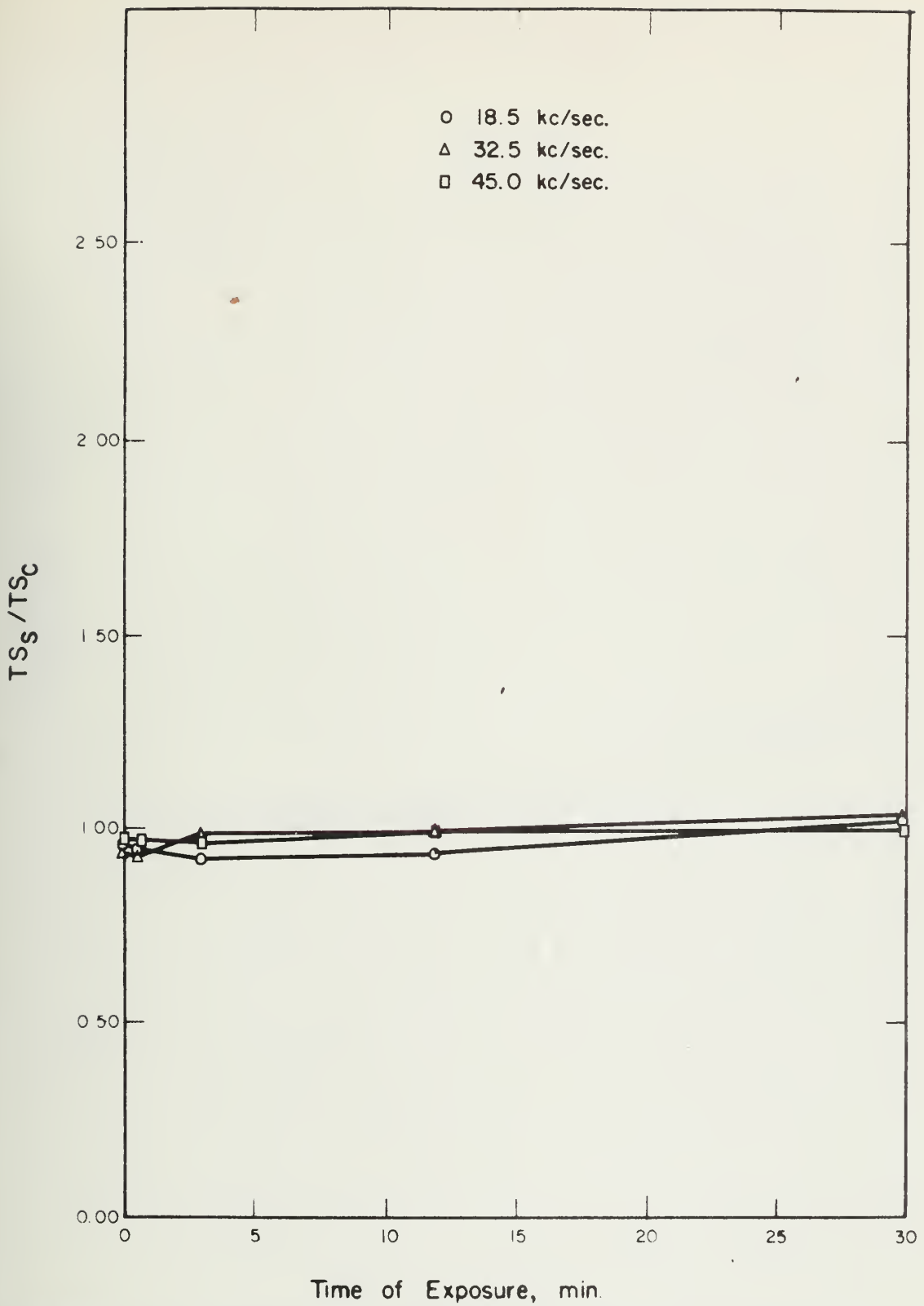


FIGURE 25. CHAMPAIGN - URBANA ACTIVATED SLUDGE TS_S / TS_C VS TIME OF EXPOSURE AT 25 WATTS.

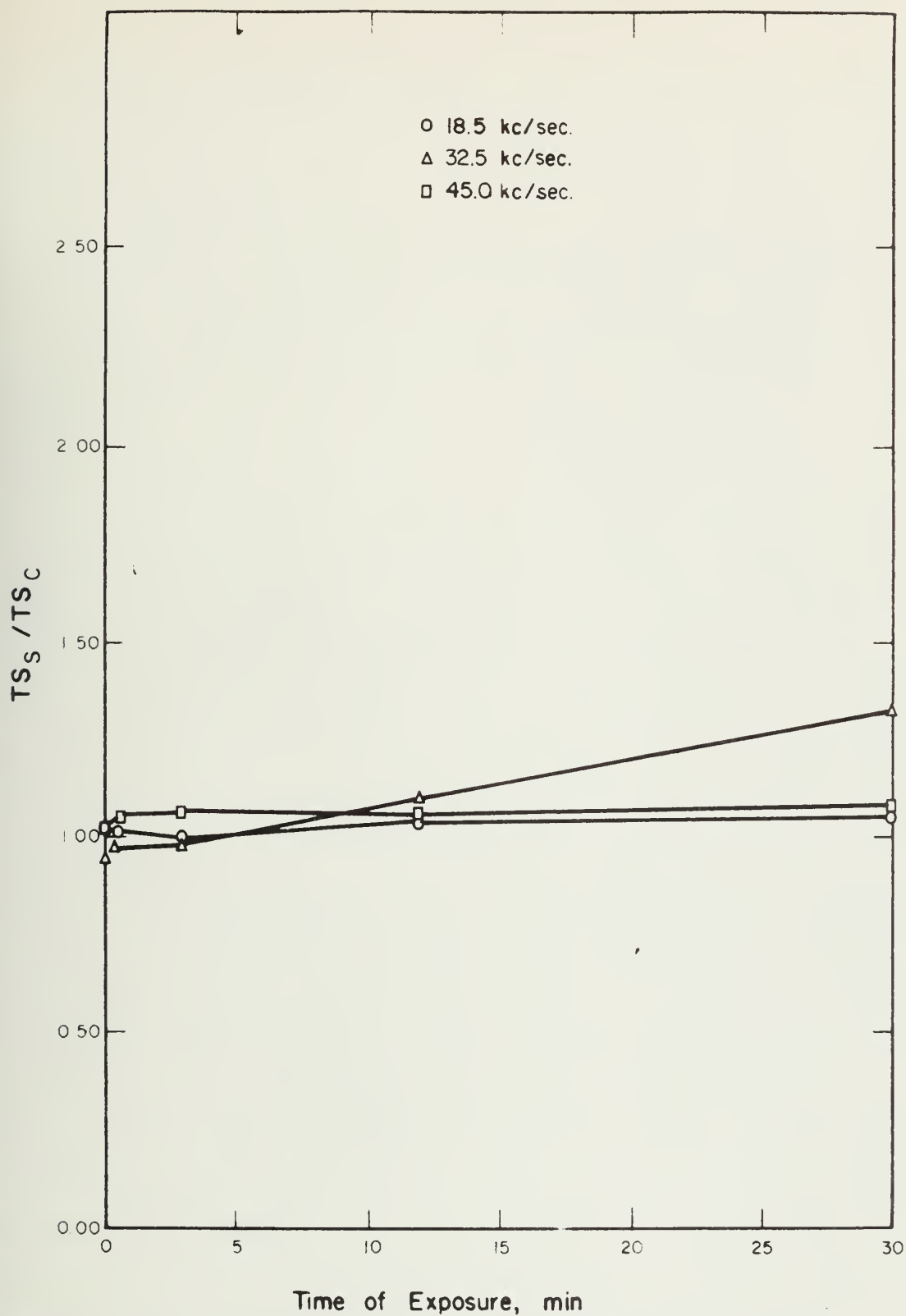


FIGURE 26. CHAMPAIGN - URBANA AERATED RETURN SLUDGE TS_S / TS_C VS TIME OF EXPOSURE AT 25 WATTS.

The three experimental variables, which were described in Chapter 2, are discussed further in this section. They are discussed relative to their effect on the ratio BW_s/BW_c . This ratio, which is the bound water multiple of the sample exposed to ultrasonic vibrations (BW_s) divided by the bound water multiple of the sample used as the control (BW_c), was utilized to prevent any natural change in the sludge characteristics from affecting the final results.

5.5.2 Power Applied

An increase in the power input did not produce a reduction in BW_s/BW_c as was theorized in Chapter 1. In fact, as can be seen in Figures 27 and 28, an increase in BW_s/BW_c resulted when studying Champaign-Urbana Activated Sludge and Sullivan Activated Sludge. It is interesting to note that while BW_s/BW_c was increasing with time of exposure for the Champaign-Urbana Activated Sludge and the Sullivan Activated Sludge, the same was occurring with TS_s/TS_c , as shown in Figures 29 and 30. This leads to a possible solution to the problem of the bound water multiple increasing, not decreasing, as past studies would indicate for sludges with decreasing sludge indexes (Heukelekian and Weisburg, 1956), as illustrated in Figures 31 and 32. *The increases in BW_s/BW_c referred to in this section (5.5) relate to changes after 30 sec of exposure. This was done to circumvent the irregular results obtained for zero exposure to ultrasonic vibrations. Microorganisms present in the heterogeneous activated sludge flocs are known to be covered with a complex polysaccharide and polyamine capsular material (Dubos, 1947). This capsular material is exposed to the liquid medium only on the outer surface. It is believed by the author that the ionized molecular groups on the surface of

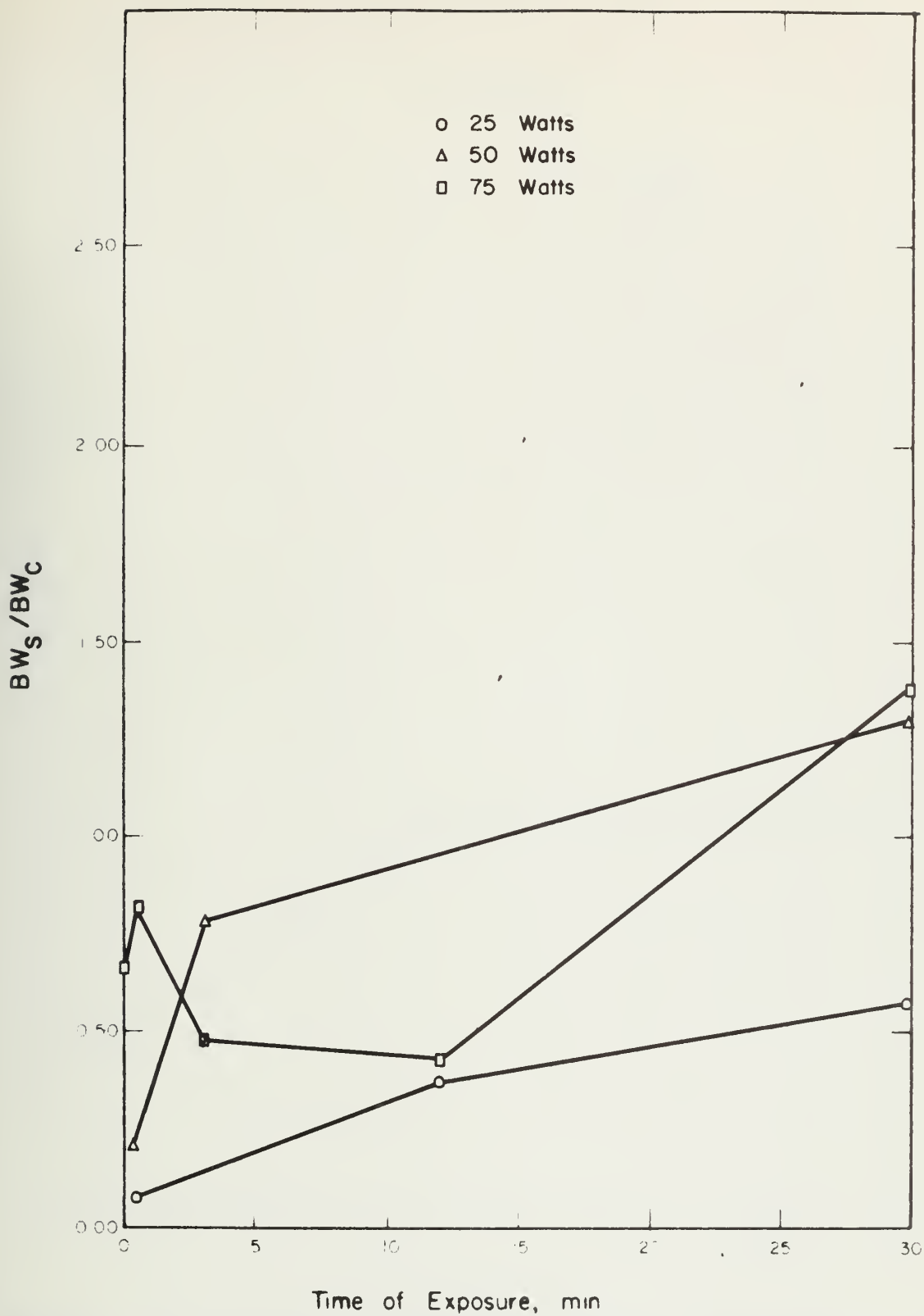


FIGURE 27. CHAMPAIGN - URBANA ACTIVATED SLUDGE BW_S / BW_C VS TIME OF EXPOSURE AT 18.5 KC/SEC.

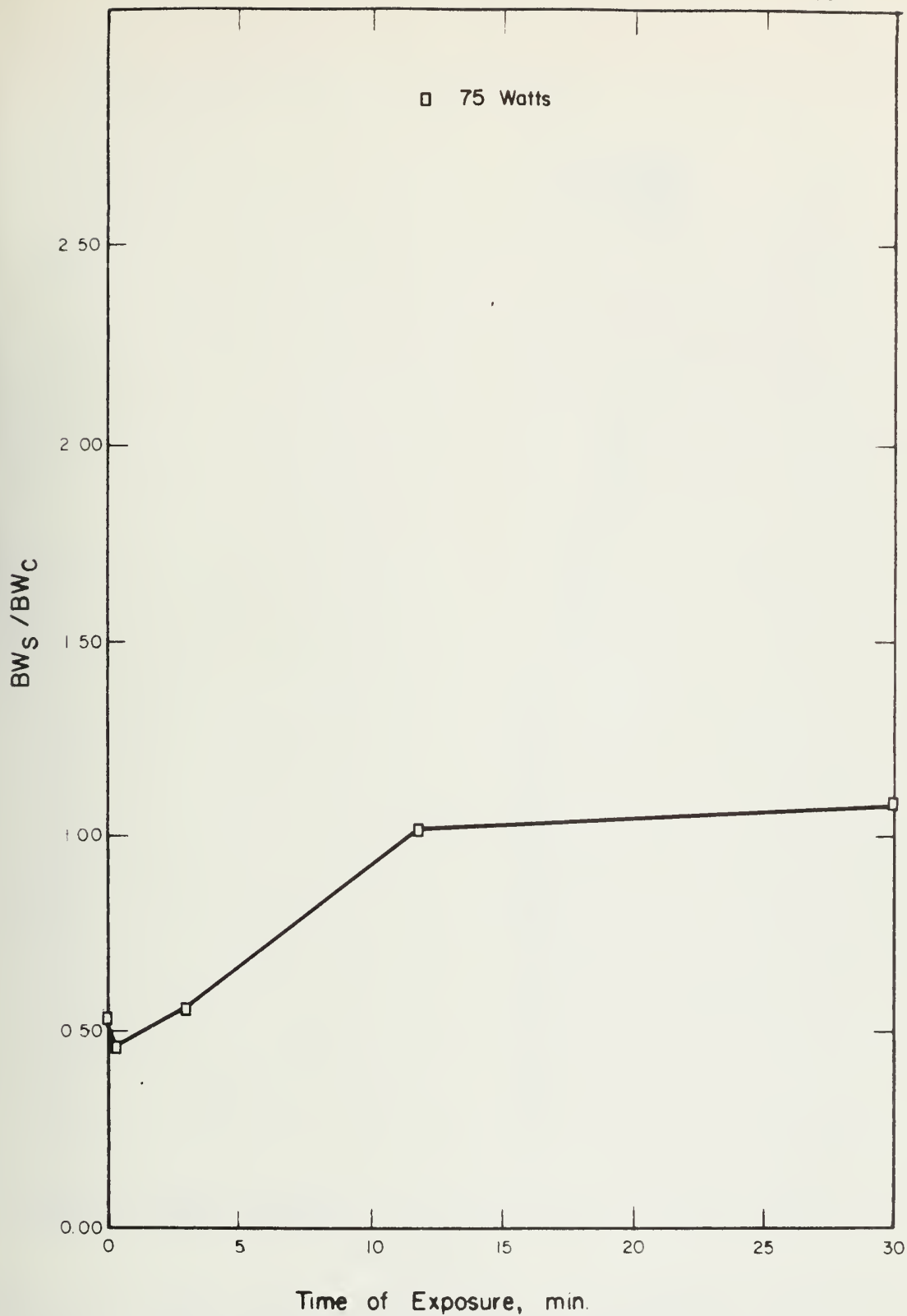


FIGURE 28. SULLIVAN ACTIVATED SLUDGE BW_S / BW_C
VS TIME OF EXPOSURE AT 18.5 KC/SEC.

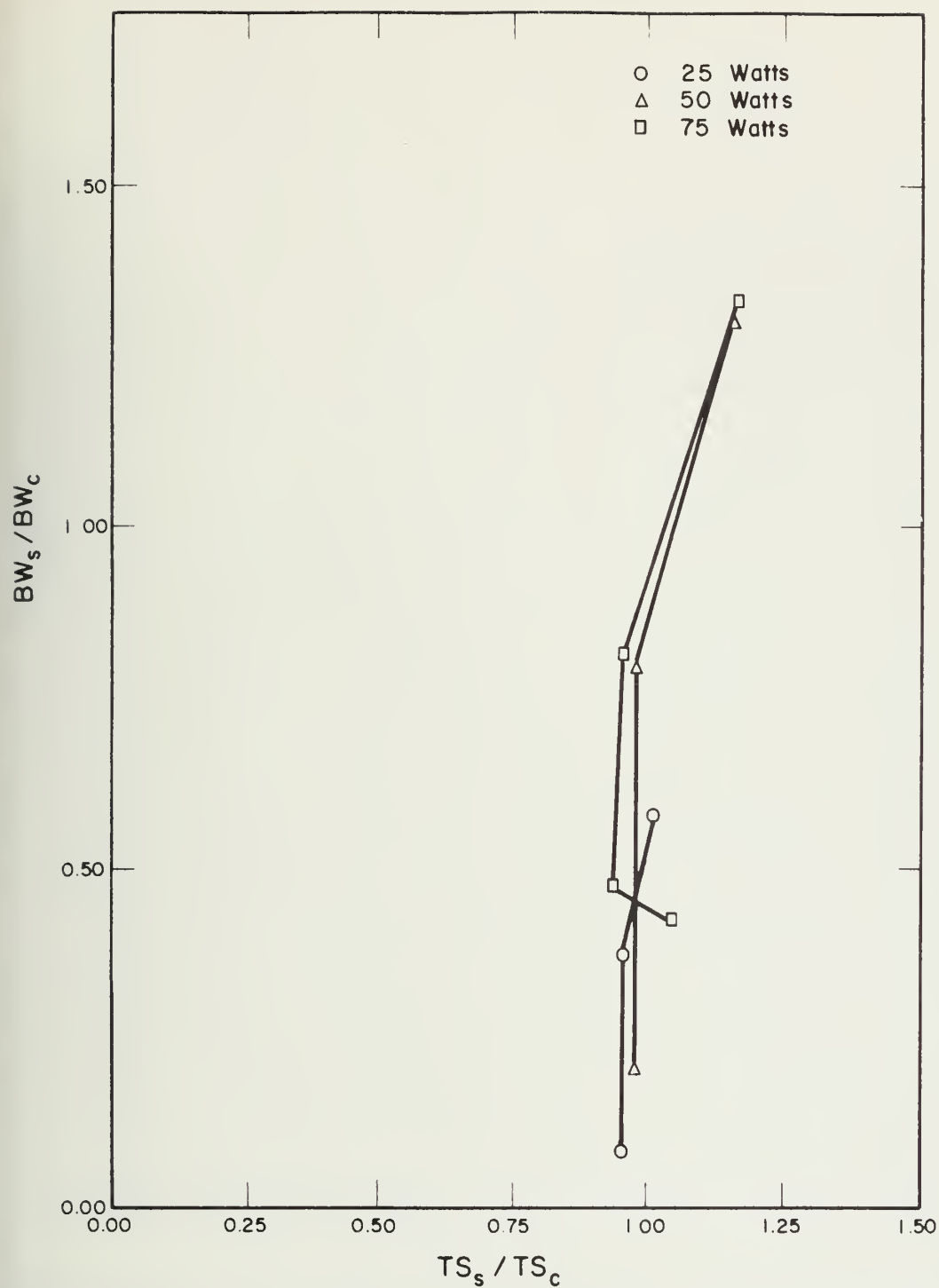


FIGURE 29. BW_S / BW_C vs TS_S / TS_C , CHAMPAIGN—URBANA ACTIVATED SLUDGE AT 18.5 KC/SEC.

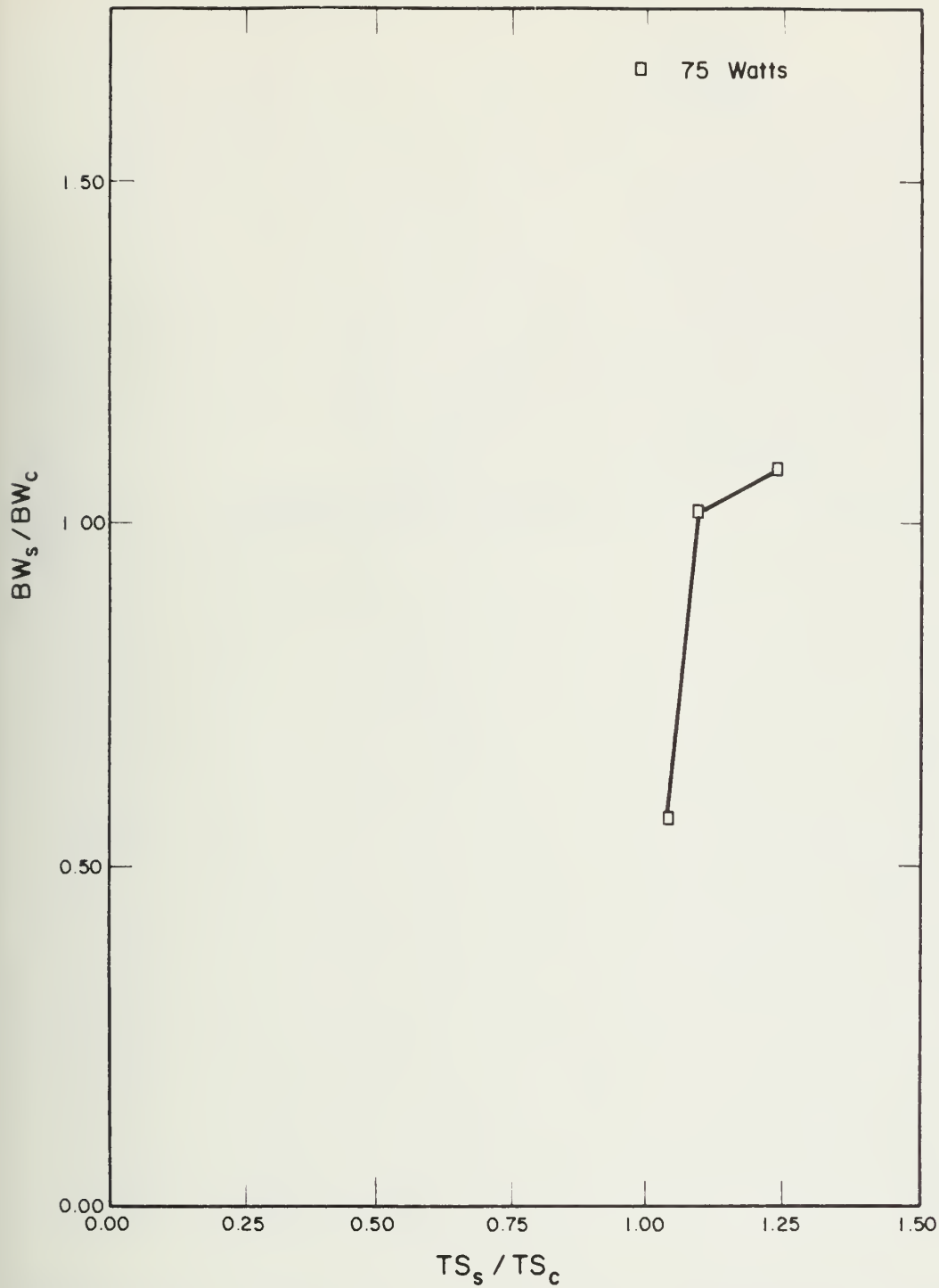


FIGURE 30. BW_s / BW_c vs TS_s / TS_c , SULLIVAN
ACTIVATED SLUDGE AT 18.5 KC/SEC.

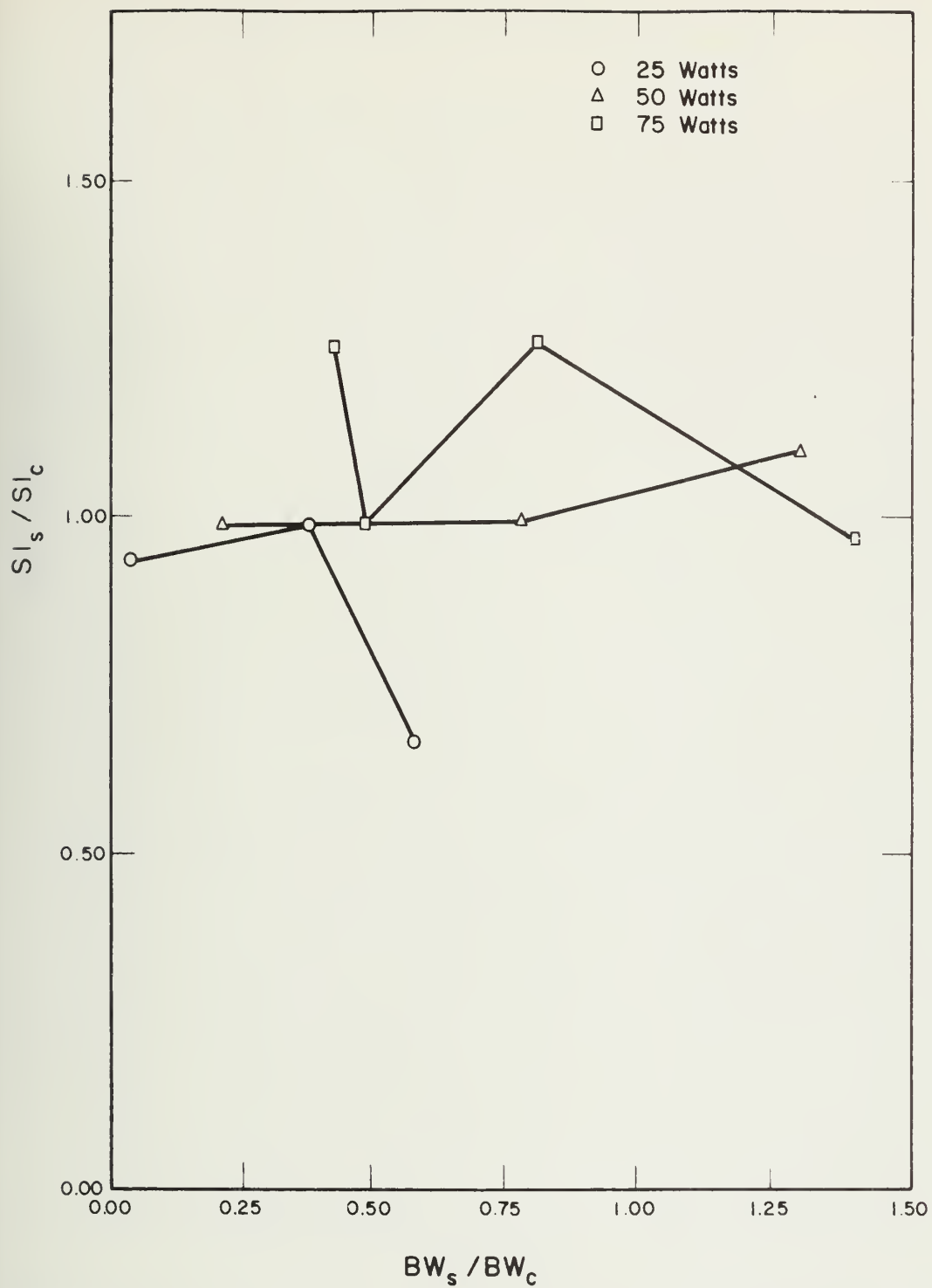


FIGURE 31. SI_s / SI_c vs BW_s / BW_c , CHAMPAIGN-URBANA ACTIVATED SLUDGE AT 18.5 KC/SEC.

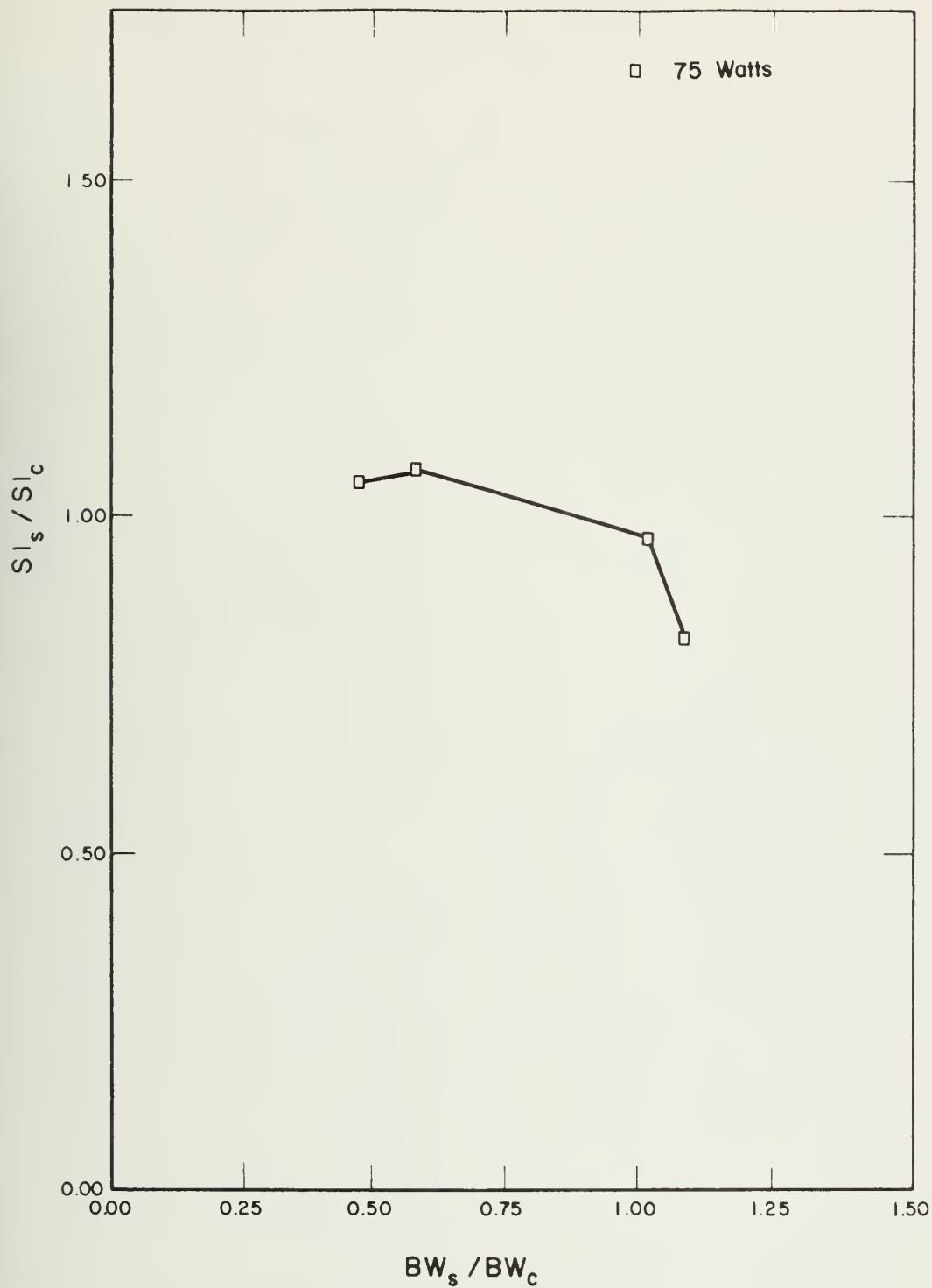


FIGURE 32. SI_s/SI_c vs BW_s/BW_c , SULLIVAN
ACTIVATED SLUDGE AT 18.5 KC/SEC

This capsular material attracts the polar water molecules. The study by Heukelekian and Weisburg (1956) supports this belief. The water may, in fact, become attached or bound to the organism via the capsular material; thus, an increase in the effective size of the organism results. Since the effective size is larger, it would follow that the organisms when settled would not form a sludge with as high a concentration as would the organism without the coating of capsular material and bound water. The capsular material may be sheared off during the intense ultrasonic agitation (Juni and Eym, 1964 and Crabtree et al., 1966). It must be pointed out that no confirmation analyses were made to determine whether polysaccharide capsular material was actually sheared off, however. Even though the capsular material was supposedly sheared off the flocculent organisms or was not present initially, Figures 12, 13, and 14 indicate, with two exceptions, that the sludge index decreased with increasing time of irradiation. The two exceptions are shown in Figure 12. This implies that capsular material is not necessary for satisfactory flocculation and is supported by studies of Dienert (1935), McKinney and Weichlein (1953), McKinney (1956), Edwards (1935) and Crabtree et al. (1966). The total solids in the supernatant were monitored to detect whether the capsular material and other solids were sheared from the organisms. As was discussed in Sections 5.4.2 and 5.4.4 the total solids did increase with time of exposure and with power applied in essentially every case. It has been theorized that sites for the water to become bound existed on the capsular material prior to being sheared off (Heukelekian and Weisburg, 1956). Therefore, the author suggests that this capsular material, once sheared off the organism, provided many more sites for the water to become attached or bound. This would cause the bound water to increase in the Champaign-Urbana

Activated Sludge, as can be seen on Figures 27 and 28.

There is very little, if any, increase in BW_s/BW_c for Champaign-Urbana Aerated Return Sludge even though there was a large increase in TS_s/TS_c , as illustrated in Figures 33 and 23. Little can be concluded from a plot of BW_s/BW_c vs TS_s/TS_c for Champaign-Urbana Aerated Return Activated Sludge, as illustrated in Figure 34. This increase was assumed to have been caused by inorganic solids and dead cell remains being shaken loose from the bacterial cells. As mentioned earlier in the case of Champaign-Urbana Activated Sludge and Sullivan Activated Sludge the total solids in the supernatant probably consisted of dissolved solids, inorganic solids, dead cells remains and polysaccharide capsular material. In the case of Champaign-Urbana Aerated Return Sludge, the sites available for bound water did not increase after exposure to ultrasonic vibration as evidenced by a negligible increase in BW_s/BW_c . The author theorized that even though TS_s/TS_c increased for the Champaign-Urbana Aerated Return Sludge, BW_s/BW_c essentially did not increase as a result of the lack of polysaccharide capsular material. The ratio, SI_s/SI_c for Champaign-Urbana Aerated Return Sludge, increased with increasing BW_s/BW_c ratios, as illustrated in Figure 35. The curve for the highest power application, 75 watts, is the lone, unexplained exception to this.

5.5.3 Frequency

Little can be concluded from the results of this area of study as presented in Figures 36 and 37. Based on the discussion in the preceding section, there should be little or no change in BW_s/BW_c for Champaign-Urbana Activated Sludge since there was very little change in TS_s/TS_c as illustrated

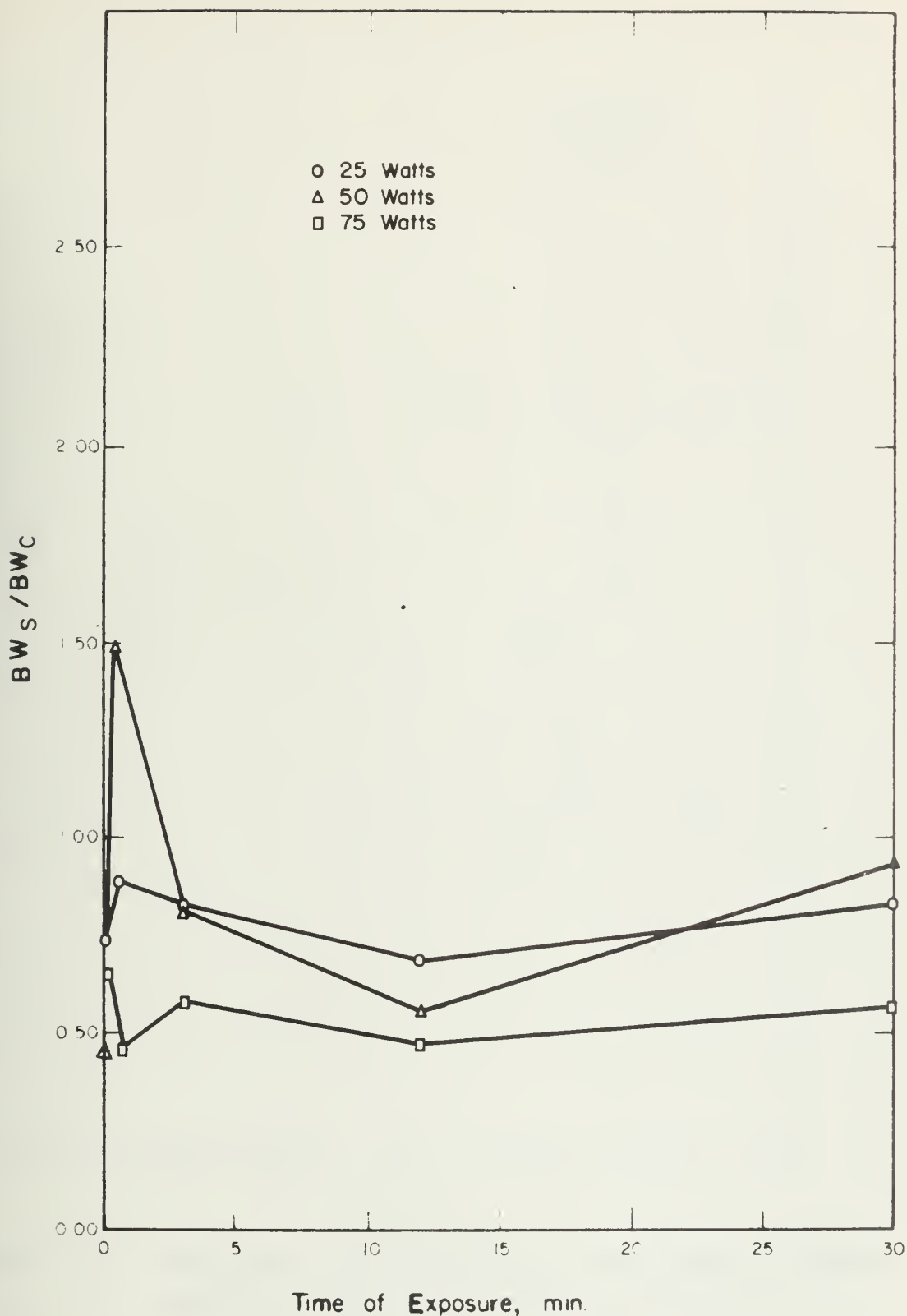


FIGURE 33. CHAMPAIGN - URBANA AERATED RETURN SLUDGE BW_S / BW_C VS TIME OF EXPOSURE AT 18.5 KC/SEC.

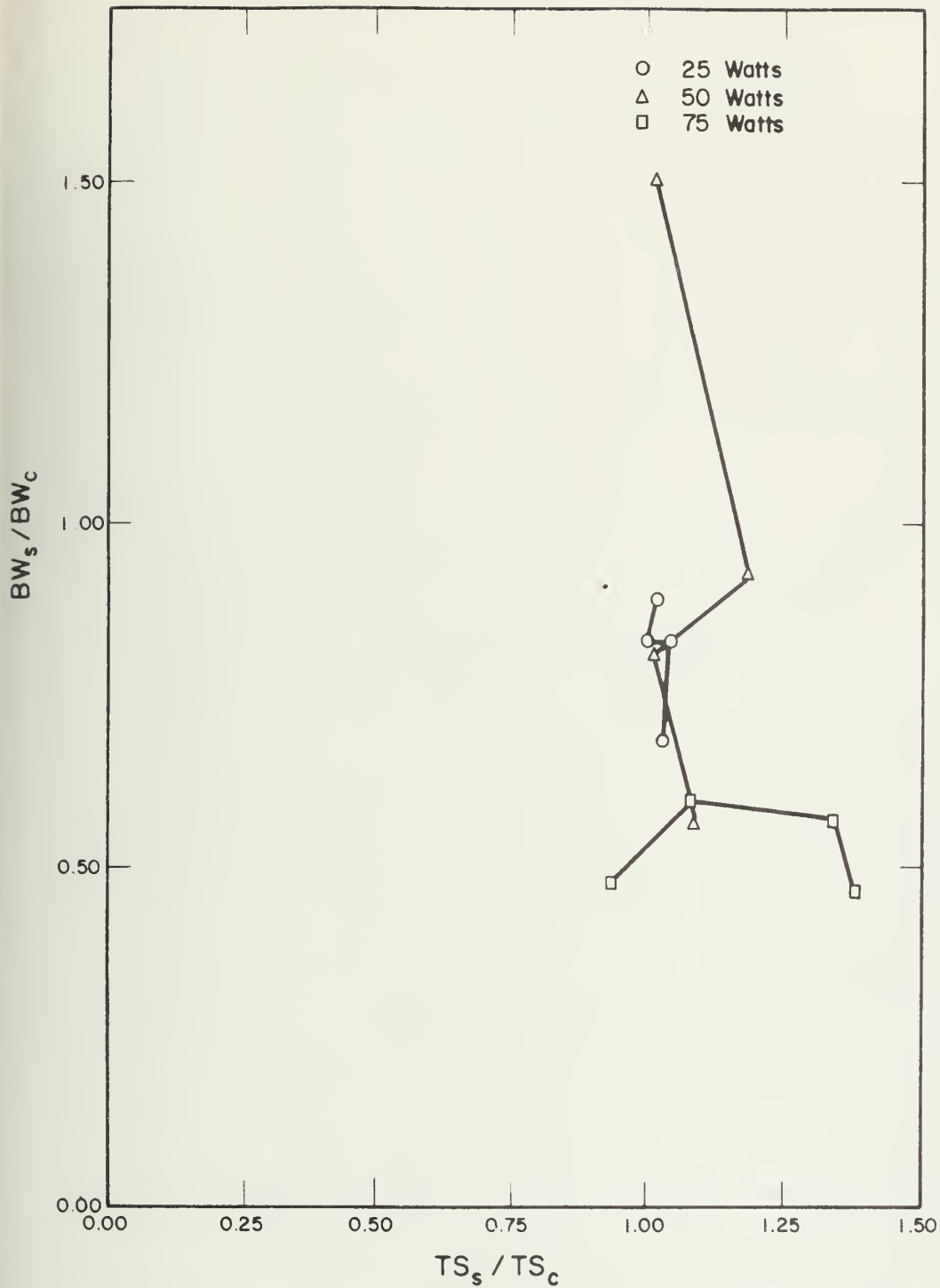


FIGURE 34. BW_s/BW_c vs TS_s/TS_c , CHAMPAIGN-URBANA AERATED RETURN SLUDGE AT 18.5 KC/SEC.

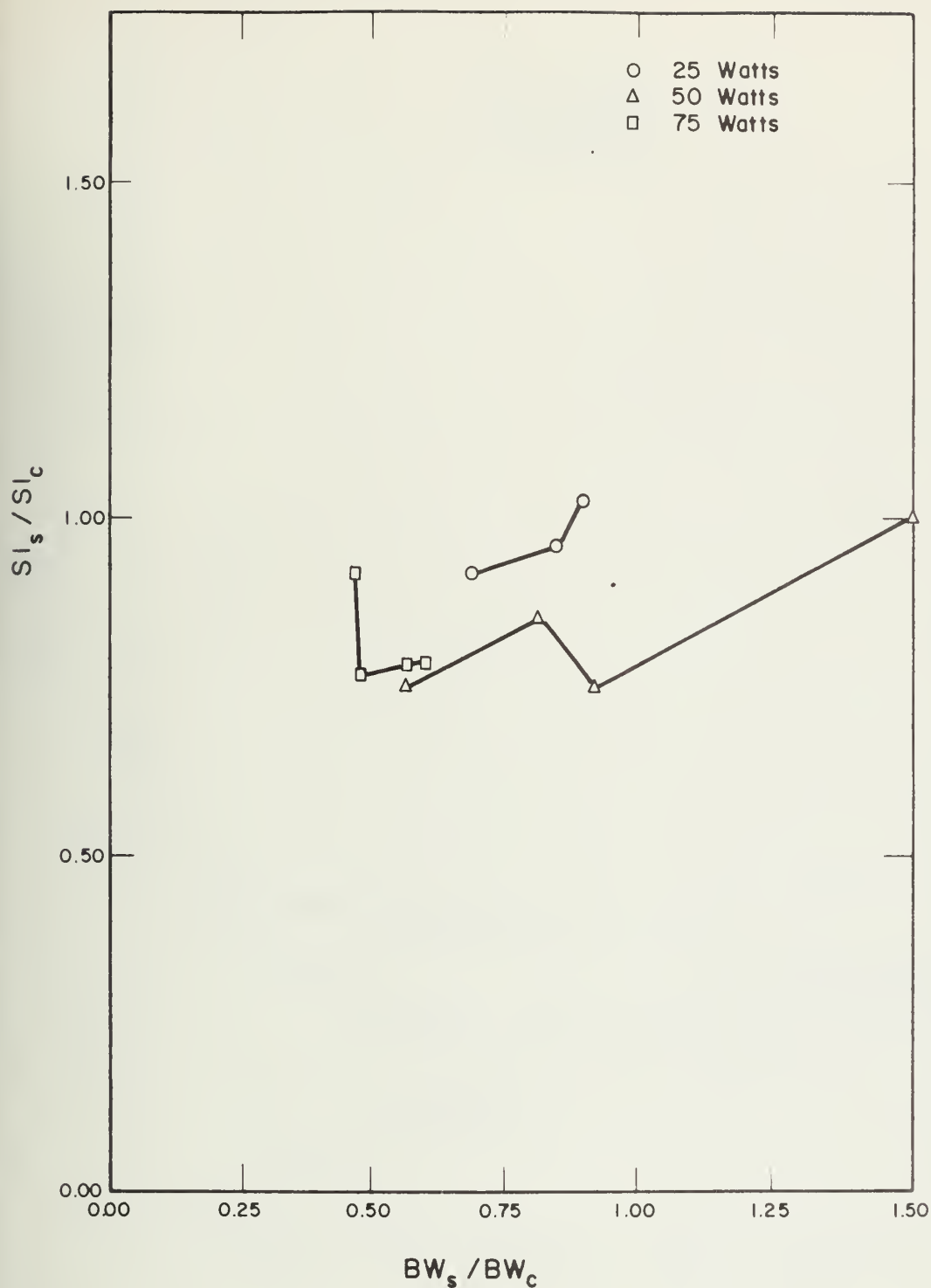


FIGURE 35. Sl_s / Sl_c vs BW_s / BW_c , CHAMPAIGN-URBANA AERATED RETURN SLUDGE AT 18.5 KC/SEC.

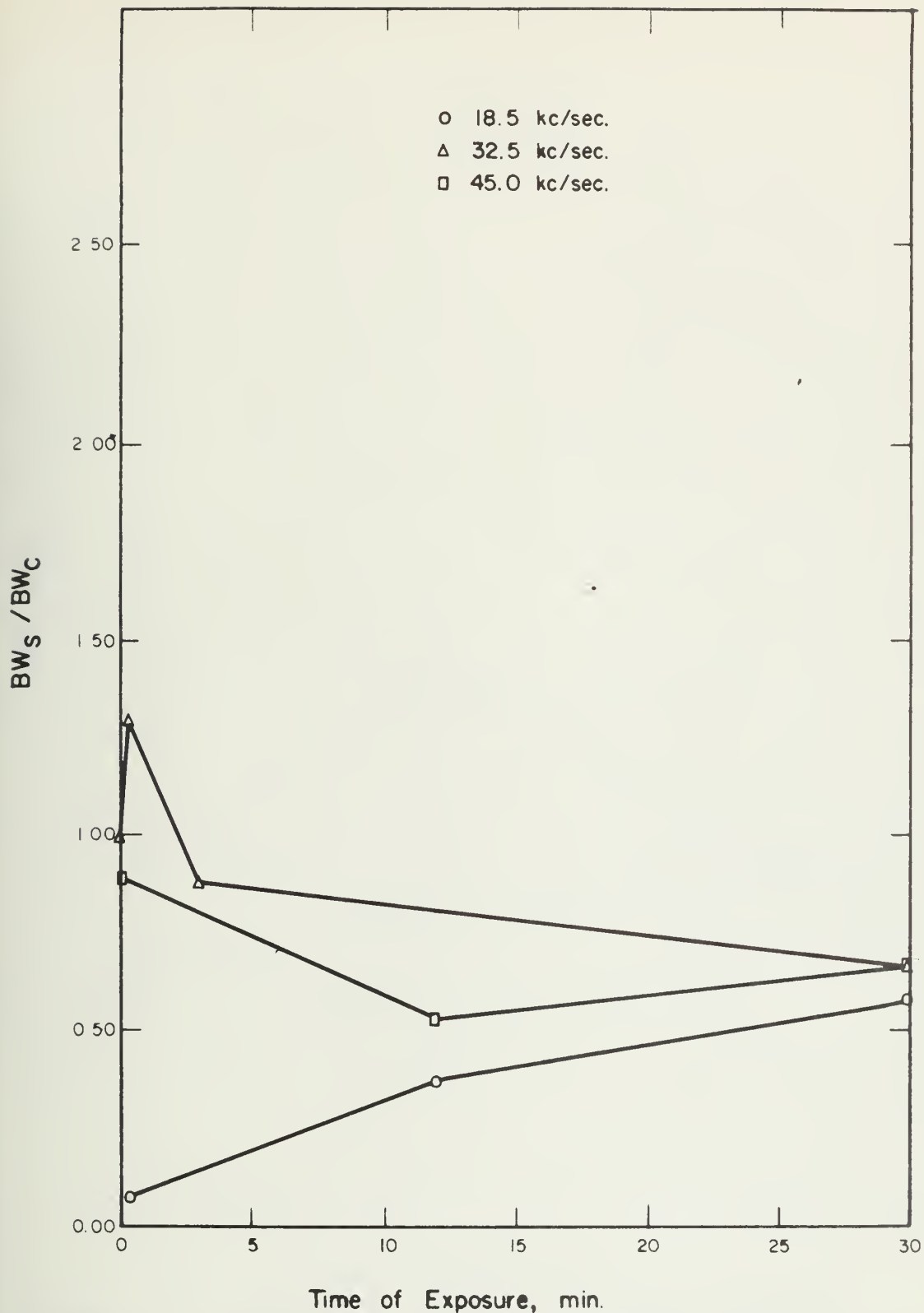


FIGURE 36. CHAMPAIGN - URBANA ACTIVATED SLUDGE BW_S/BW_C VS TIME OF EXPOSURE AT 25 WATTS.

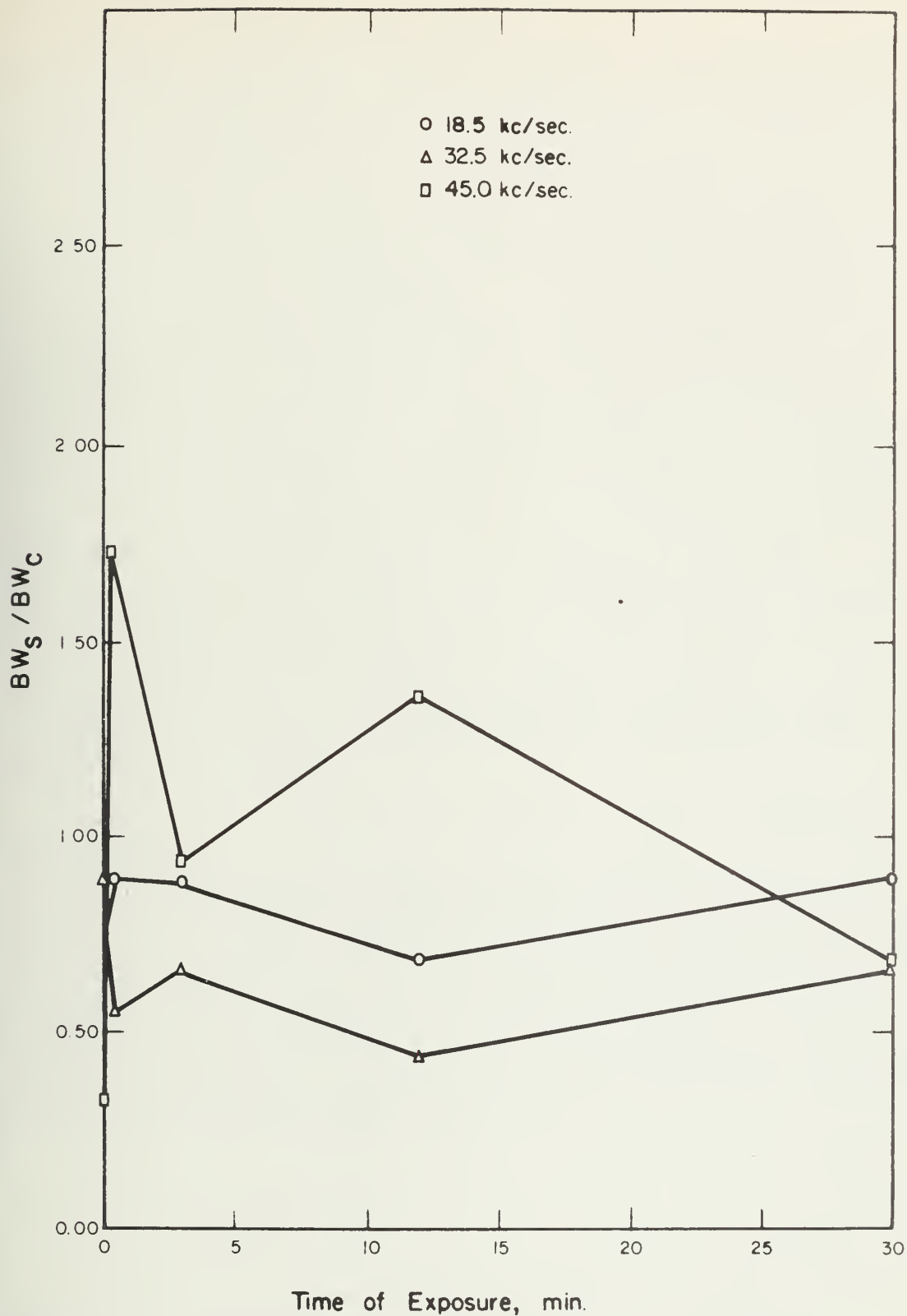


FIGURE 37. CHAMPAIGN - URBANA AERATED RETURN SLUDGE BW_S / BW_C VS TIME OF EXPOSURE AT 25 WATTS.

in Figure 25. There was a small increase, 10 percent, in TS_s/TS_c for the sample exposed to the lowest frequency. Although there was a recognizable increase in TS_s/TS_c for the other two samples, they increased only approximately half as much as did the samples exposed to the lowest frequency. This could have been a result of inorganic solids dead cell remains and polysaccharide capsular material being shaken loose from the cell surface. While the sample exposed to the lowest frequency was agitated thoroughly enough to shear off additional material into the liquid medium, the samples exposed to the higher frequencies probably were not agitated as violently. As a result of this, it is likely that this gentle agitation promoted additional flocculation thus reducing the sites available for bound water.

Very little can be concluded from the studies involving the effect of the frequency of vibration on Champaign-Urbana Aerated Return Sludge. These results were very erratic.

5.5 Time of Exposure

It is obvious from the preceding results that the effect of the length of exposure on BW_s/BW_c is dependent on the nature of the sludge being exposed to the ultrasonic vibrations. The ratio, BW_s/BW_c , for Champaign-Urbana and Sullivan Activated Sludge increased; whereas BW_s/BW_c of Champaign-Urbana Aerated Return Sludge changed very little.

CHAPTER 6. SUMMARY

There was no clear cut optimum power input level. As described in Section 2.1.2, the effects of ultrasonic vibrations on SI_s/SI_c ranged from deleterious to beneficial depending on the particular activated sludge being studied at the time. With a well settling activated sludge ($SVI < 90$) ultrasonic vibrations were effective only at lower power applications. This was thought to be a result of bubbles, formed during cavitation, buoying up the settling sludge. Ultrasonic vibrations proved to be beneficial when exposed to an endogenous activated sludge such as Champaign-Urbana Aerated Return Sludge. High power applications were effective in reducing SI_s/SI_c of a filamentous type bulking sludge such as the Sullivan Activated Sludge.

The only conclusion made from the effect of various frequencies of vibration is that, generally, lower frequencies proved to be the most effective in reducing SI_s/SI_c .

The time of exposure was important because, with few exceptions, prolonged exposure to ultrasonic vibrations produced reductions in SI_s/SI_c . Therefore, the longest time of exposure was generally the most effective.

The summary statements made concerning SI_s/SI_c are also applicable to V_s/V_c in that when V_s/V_c increases, SI_s/SI_c will decrease.

The total solids in the supernatant increased as the power applied increased, as the frequency decreased and as the time of exposure increased. This was attributed to: an increased resistance experienced by the sludge particles with the suspending medium; a release of powerful pulses as the cavities collapsed; an ultrasonic wave with a low frequency of vibration, which was not attenuated readily, and a sufficiently long time of exposure to allow the ultrasonic vibrations to be effective in removing polysaccharide

capsular material and other attached colloidal and insoluble solids from the microorganisms. Perhaps some microorganisms were lysed, also.

The bound water ratio, BW_s/BW_c , increased with time of exposure for Champaign-Urbana Activated Sludge and Sullivan Activated Sludge, when subjected to an adequate or an abundant nutritional environment, see Appendix A; whereas, BW_s/BW_c changed very little for the Champaign-Urbana Aerated Return Sludge, which was probably sampled in the endogenous phase of growth. This is probably due to the fact that the organisms with an adequate nutritional environment may be coated with a polysaccharide capsular material, which may, in turn, be agitated loose by ultrasonic vibrations. The detached capsular material provided additional sites for water to become bound. Although TS_s/TS_c increased for an endogenous activated sludge such as the Champaign-Urbana Aerated Return Sludge, the solid material shaken loose from the sludge organism probably contained little polysaccharide capsular material as evidenced by the negligible increase in BW_s/BW_c .

It should be pointed out that while the discussion of the effects of ultrasonic vibration is based in this paper on the physical condition of the sludges, the possibility exists that the various suspended solids concentrations may have been partially responsible. This is doubtful in the author's mind, however, in light of the studies of Lyon (1952) and Schulte (1964).

CHAPTER 7. CONCLUSIONS

1. Ultrasonic vibrations may or may not improve the settleability of activated sludge; this depends on the recent history of the sludge in question.

2. For activated sludge originally with poor settling characteristics, the power input of 75 watts was most effective in improving the settleability.

3. The lowest frequency available, 18.5 kc/sec, generally was the most effective in improving the settleability of the activated sludges originally with good settling characteristics.

4. Due to the solids that are agitated loose from the activated sludge and possibly the lysing of some bacterial cells, the total solids in the supernatant increased considerably upon exposure to ultrasonic vibrations. Increases of 6 percent to 43 percent were observed, depending on the power level utilized. Greater increases occurred with greater power applications.

5. Exposure of activated sludge with an adequate nutritional environment to ultrasonic vibrations resulted in considerable increases of BW_s/BW_c ; whereas, exposing an activated sludge with a limiting nutritional environment resulted in negligible increase in BW_s/BW_c .

6. A supercooled alcohol solution was more economical and easier to use than dry ice for determining bound water.

CHAPTER 8. SUGGESTIONS FOR FUTURE WORK

In view of the studies described herein, there are several items worthy of future study. The following are considered to be noteworthy by the author:

1. Due to the considerable amount of time required to develop the necessary equipment for this research, below are listed the items that were not considered during the actual research because of a time shortage; however, they should be considered before this work can truly be considered complete.

a. Effect of ultrasonic vibrations on the flocculation of activated sludge should be studied.

b. Do the bubbles, which are formed during cavitation, actually become attached to the microorganisms rich in PHB?

c. Is polysaccharide capsular material shaken loose from the microorganisms?

d. To what extent did lysed cells add to the total solids in the supernatant?

e. Did the bound water actually become attached to the polysaccharide capsular material?

2. A study to determine whether exposing activated sludges to ultrasonic vibrations is economically feasible should be undertaken.

3. Research aimed at determining the accuracy of the dilatometer method for determining the bound water of activated sludges is of primary importance.

4. Establish whether or not the solubility of toluene affects its usefulness as an indicator liquid.

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APPENDIX A - SOURCE OF ACTIVATED SLUDGE

1.0 Champaign-Urbana Sanitary District

1.1 General

The availability of the Champaign-Urbana Sanitary District's activated sludge and the differences in the physical properties of the sludges under aeration made this an ideal source of activated sludge for the purpose of this study.

1.2 Activated Sludge

This facility operates on a modified contact stabilization process utilizing approximately 3.5 hours for contact with the raw sewage as compared with 20 to 40 minutes for the conventional contact stabilization process. The contact phase of this process was referred to as Champaign-Urbana Activated Sludge. The suspended solids concentration was maintained at approximately 1700 mg/l with a loading rate (food-to-microorganism ratio, F/M, for all the sludge under aeration of $.192 \text{ day}^{-1}$). Due to a relatively short period for stabilization of the sewage in this phase of aeration, this sludge was thought to be in a growth phase.

1.3 Champaign-Urbana Aerated Return Sludge

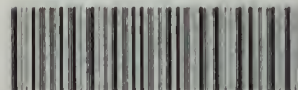
The stabilization phase, which will henceforth be referred to as Champaign-Urbana Aerated Return Sludge, consists of approximately 9 hours of aeration as compared with 6 hours normally provided for the stabilization of organic material. Since the period allowed for stabilization is rather long, the author considers himself to be justified in assuming that the sludge when taken from the sewage treatment plant was in the endogenous phase of growth.

2.0 Sullivan Activated Sludge

The Sullivan Activated Sludge, at the time the sample was removed from the sewage treatment plant was exposed to a very high BOD loading consisting of starch and soluble sugars from a candy industry located in the municipality. The loading rate (F/M) for this facility was calculated to be $.41^{-1}$ days. As a result of the high F/M and the possibly improper nutrient balance, a bulking sludge was produced with a sludge volume index (SVI) (Standard Methods, 1965) of greater than 400.

The Sullivan Activated Sludge was chosen because it was thought that the bulking was caused by an excess amount of bound water. Heukelekian and Weisburg (1956) concluded that feeding large amounts of sugar to activated sludge would cause appreciable increases in the bound water content and in the SVI. However, a microscopic investigation of the Sullivan Activated Sludge revealed a filamentous type microorganism present in a considerable concentration.

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